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Occurrence of Arsenic in Groundwater at Kandal Province, Cambodia

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Abstract: Concentration of arsenic in groundwater was investigated at three villages (Chong Prek, Prek Tameng and Prek Thom) in the Kandal Province of Cambodia, which ranged from 80.9 μg/L (in Prek Tameng village) to 1420 μg/L (in Prek Thom village), with average and median concentrations of 463.16 and 217 μg/L, respectively. Iron concentration was also determined. Nearly all the twenty-five samples contained arsenic and iron concentrations exceeding the WHO drinking water guidelines (100% As > 10 μg/L, 100% Fe > 300 10 μg/L) and the Cambodian legal limits of drinking water (100% As > 50 μg/L, 100% Fe > 1000 μg/L). The sources of arsenic occurrence were studied trying to explain in terms of geogenic origin based on the available data. The As release into groundwater may result from the reductive dissolution of metal oxides under reducing condition at circum-neutral pH, in particular iron sulfide (*pyrite*), according to the evidences of iron, sulfate, phosphate, nitrate and nitrite in the groundwater, measured by ICP-AES and IC. This study showed that the occurrence of arsenic in Kandal Province poses a health threat to the villagers in Kandal Province and appropriate treatment of groundwater must be implemented.

Keywords: Arsenic, Iron, Groundwater, Kandal Province.

Introduction

Cambodia is documented as one of the world's most affected countries by elevated arsenic in groundwater. The elevated concentrations of arsenic are distributed in several provinces, such as Kandal, Prey Veng, Kratie, Kampot, and south-eastern parts of the country [4; 5; 6; 9; 11]. Recently, several studies related to the occurrence of As in groundwaters of Cambodia have been reported and focused on the spatial and hydrogeological distributions of As [13; 12; 2], its release mechanisms [16; 15; 19], environmental study related to hazard prediction [10], and health risks and assessment of the residents due to cumulative arsenic intake [17; 8; 11; 18]. Some studies also indicated policy response to the residents including those who are not able to afford the cost of tap water and the convenient filters [17; 14]. Moreover, most of the researches were conducted in Kandal Province, which was found to be the most highly risked province in Cambodia due to the significantly high concentrations of arsenic and other trace elements (Fe, Mn, Pb, Ba, Sr) in groundwater, which are exceeding the WHO guidelines and the Cambodian legal limits [11; 18]. The lack of adequate information regarding the presence of As and other trace elements in groundwater which is the only readily available water resource for consumption has led to the occurrence of a number arsenicosis and hyperkerotosis cases among the residence of the affected areas. Hence, such reported incidence caused some people to stop using the water from the tube well for drinking and use the tap water instead which is more expensive.

Arsenic contamination of groundwater is a serious environmental and health concern not only in Cambodian but to other places such as in Bangladesh and West Bengal (India), Vietnam, Thailand and Myanmar [3; 13], especially in rural areas where most of the residents largely depend from tube well waters for drinking [4; 6].

The occurrence of concentrated amount of As in Cambodian groundwater was attributed to the reducing condition in the accumulated sediments along the Mekong River which caused the dissolution Fe oxide minerals with adsorbed As. The dissolution of Fe bearing minerals led to the release/mobilization of arsenic into the groundwater. This release mechanism was also observed in Bangladesh and other affected countries [19; 16; 15].

This study investigated the occurrence of As in groundwater at Kandal Province, Cambodia. In the present study, the concentration of As in various tube-wells was determined in order to assess the current level of exposure of the residents in Kandal Province. To understand the geogenic origin of As in Cambodian groundwaters, the concentration of Fe and other elements such as sulfate, nitrate and nitrite were also determined.

Materials and Methods

Sample collection

Twenty-five tube-well water samples were collected in mid-March, 2009 from three villages (CP (*n* = 4), PM (*n*

= 11), PT (n = 10)) in Kandal Province: *(i)* Chong Prek Village, Prek Sdey Commune, Koh Thom District; *(ii)* Prek Tameng Village, Prek Sdey Commune, Koh Thom District; and *(iii)* Prek Thom Village, Kbal Koh Commune, Kien Svay District. Chong Prek and Prek Tameng villages lie along the Basak River to the south, while Prek Thom village is located along the southern bank of the Lower Mekong River (Figure 1). During the sample collection, the tube-well waters were pumped for several minutes before starting the collection and the *in-situ* measurements. At each tube-well, two 50 mL polypropylene bottles were washed three times with tube-well water (and so with the syringes) before the filtered water was placed in the bottles. The tube well water was filtered using 0.45 µm cellulose nitrate filters. One of the bottles was used to store the water with 1% of nitric acid (HNO_3) for cation analysis. The other bottle containing water samples without nitric acid was used for anion analysis.

Groundwater analyses

During water sampling, the direct measurements of the water quality of tube-well waters were performed. The pH, temperature (tº), electrical conductivity (EC), and oxidation/reduction potential (ORP) values were measured by portable calibrated water meters and then recorded on-site. The acidified waters (1% of HNO_3) were analyzed for arsenic and iron concentration using inductively coupled plasma–atomic emission spectrometry (ICP–AES: ICPE-9000 Shimadsu, Japan). The measurement of anionic species of the water samples such as F^-, Cl^-, NO_2^-, Br^-, NO_3^-, PO_4^{3-}, SO_4^{2-} were conducted by using ion chromatography (IC).

Results and Discussion

Groundwater characteristics in Kandal Province

The chemical characteristics of groundwater in Kandal Province were presented in Table 1. The results showed that the groundwater samples were under slightly oxidizing condition as revealed by the redox potential measurements with Eh values ranging from +27 to +160 mV at circum-neutral pH condition ranging from 6.81 to 7.62.

Figure 2 (a) shows that arsenic was present in very high levels in Kandal Province. The concentrations of arsenic ranged from 80.90 (in PM village) to 1420 µg/L (in PT village), with the average and median concentrations of 463.16 and 217 µg/L, respectively. It can be seen that the arsenic concentrations in all groundwater samples exceed the WHO drinking water guidelines (10 µg/L) and the Cambodian legal drinking water limit (50 µg/L) [7]. Of the three villages, arsenic occurrence was much higher in PT village in which the lowest arsenic concentrations was 782 µg/L compared to CP and PM villages where the highest arsenic concentrations were only 181 and 254 µg/L, respectively. On the other hand, the concentrations of iron in the groundwater from Kandal Province ranged from 704 (in PT village) to 5840 µg/L (in CH village). 100% of the groundwater samples appeared to exceed the WHO guideline which is only 300-µg/L allowable and 88% of the samples were over 1000 µg/L of the Cambodian legal limit of drinking water quality standard [7]. The average and median iron concentrations were 3255 and 3680 µg/L, respectively.

Source of arsenic occurrence

Recently, the geogenic origin as a possible source of arsenic has been extensively studied. Geologically, based on the floodplain location of the Kandal Province, the geogenic source of arsenic in the Cambodian Mekong Delta, referring to the areas between the Lower Mekong River and the Basak River, was from the sedimentation of alluvial Quaternary deposits of the Upper Mekong River. Arsenic was sorbed onto the surface aquifer sediments in high concentrations, which then released to the groundwater during the dissolution of Fe oxide minerals under reducing condition [19; 16; 15; 4; 11; 18]. According to the study finding, all the groundwater samples contained dissolved Fe (0.70-5.84 mg/L), NO_3^- (<8.31 mg/L) and SO_4^{2-} (<15.84 mg/L). This could be inferred that the available O_2 and NO_3^- might have been consumed during microbial activity by possibly reducing solid phase Fe(III) to aqueous Fe(II) and reducing high SO_4^{2-} to low dissolved SO_4^{2-}. Thus, the groundwater was suggested to be in anoxic condition. By this way, As would be reduced from the sediment aquifer to the groundwater. The results showed the correlation between Fe, NO_3^-, SO_4^{2-}, and As in the groundwater and in accordance with the study of Rowland *et al.* (2008). The reductive dissolution of As-bearing metal oxides, especially pyrite, was suggested to be the possible cause of the arsenic release into the groundwater of the Kandal Province [16; 15] and Eh values would range between -500 and 0 mV at neutral pH [1]. However, this study showed that Eh values were positive, ranging between +27 and +160 mV, at near-neutral pH (Table 1). The measured Eh was unlikely the exact redox potential of groundwater; the observed elevated Eh may be attributed to the partial oxidation of the groundwater samples with the atmosphere during groundwater sampling at the well-head from the standing water and may not be representative of the redox condition within the aquifer. The actual reducing condition of groundwater could possibly be detected at the bottom of the tube-well and the Eh values would be negative. Under this condition, arsenic would mobilize in the aquifer during the flow of groundwater.

Moreover, regarding the human activities, along with the development of the Kandal Province and the increase of population, groundwater which is used to be the available resource has been continuously extracted for consumption, farming, plantations, and so forth. This might lower the groundwater table during dry season, which gives opportunities for sediments to expose to the atmosphere and arsenic rich minerals would oxidize by releasing arsenic into the groundwater over time in the history. However, this still remains unclear till now.

Exposures of arsenic and responses

Due to the occurrence of elevated concentration of arsenic in the groundwater of the Kandal Province, the groundwater was reported contaminated and the arsenic issue has been widely known as the health hazard and risk to the villagers. Sampson *et al.* (2008) have recently conducted the research by analyzing the concentrations of arsenic on the hairs, urines, and nails of the villagers. Their research results have found positive that arsenic exposure could directly lead to several arsenicosis symptoms including varicose hyperkeratosis as a result of arsenic ingestion. This can be seen as a skin cancer on the villagers, especially in Prey Russey village. The exposures of arsenic also occurred in two other villages in the Kandal Province, namely Prek Chrey village and Lvea Em village. In addition, previous research by Berge *et al.* (2007) also indicated that the villagers in Kandal Province, especially the farmers, have been facing this arsenic hazards and risks due to the reflected results of arsenic on their hair and urine samples and this symptom might develop to a serious arsenicosis if those villagers still continue drinking the arsenic-rich groundwater.

In response to the arsenic occurrence as health hazards to the villagers, the local communities have taken a number of measures on educating the targeted areas as well as on installing rainwater harvesting systems or ceramic filters at the local schools and at houses. Furthermore, some appropriate treatment for pathogens to the river water as the drinking source was taught in order to minimize the arsenic exposure to the villagers in the future (Sampson *et al.*, 2008).

Conclusions

Arsenic occurrence in the Kandal Province of Cambodia has been discovered for the last few years, since the arsenic exposure has been clearly observed due to the skin cancer on the feet and hands of the villagers. Based on the study results, arsenic and iron concentrations in nearly all groundwater samples appeared to be exceeding the WHO (100% As, 100% Fe) and Cambodian limit guidelines (100% As, 88% Fe). This has been the terrible issue for the people who live in the Mekong Delta of Cambodia and use the groundwater resource as drinking water. The surface water (river water) is known to contain pathogens, while the groundwater consists of elevated arsenic and iron. At the same time of the occurrence of groundwater contamination by the hazardous arsenic, the studies on how the arsenic could exist and where it could be originated were also conducted. The findings showed that the sources of arsenic were found from natural geogenic origin which stated that the reductive dissolution of Fe-bearing minerals in the aquifer sediment were the processes by which arsenic is released to the groundwater over time.

To sum up, this finding was an addition to what have been just discovered for more details in some ways. However, the occurrence and source of arsenic may lead us to the solution on how to treat the arsenic-rich groundwater based on the general characteristics of groundwater by using locally available resources as any possible adsorbents.

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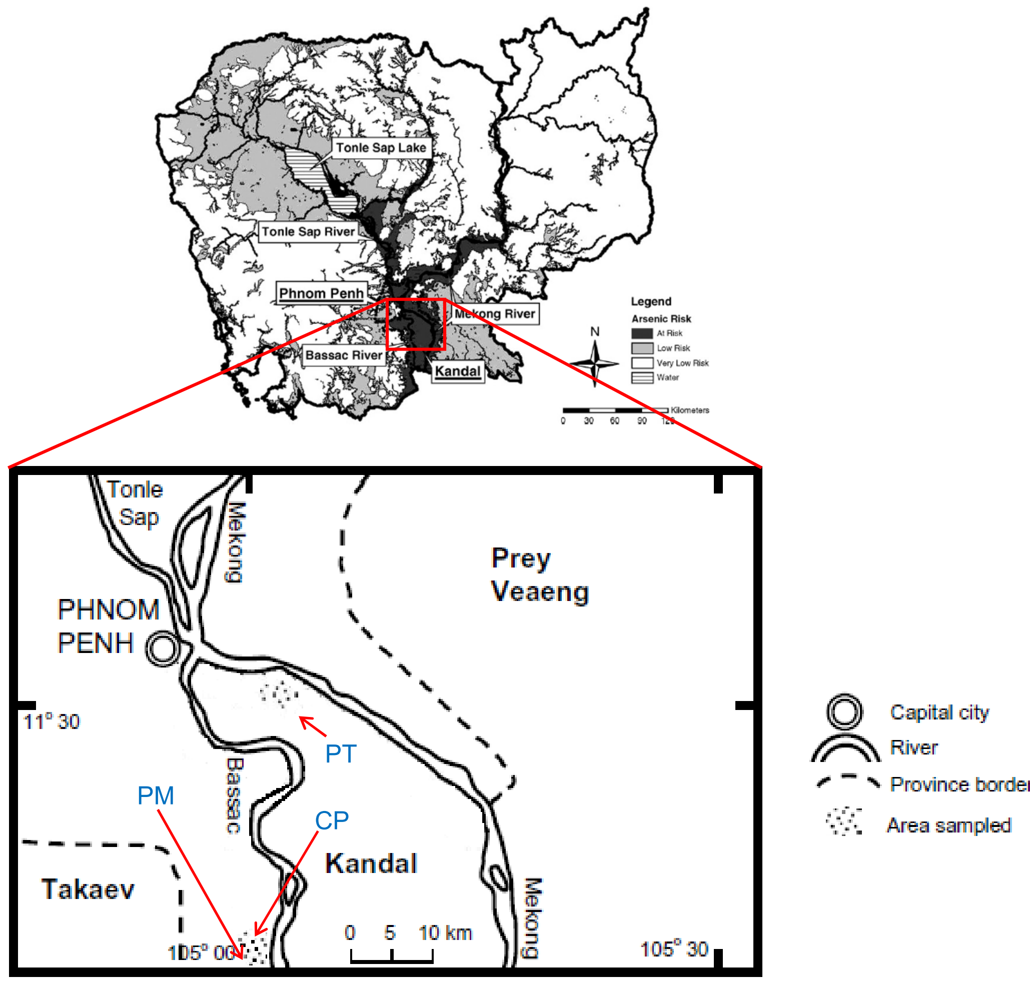


Figure 1. Map of sampling locations in Kandal Province, Cambodia: (a) Prek Thom Village (PT), (b) Chong Prek Village (CP) and (c) Prek Tameng Village (PM) (modified from Rowland et al., 2008)

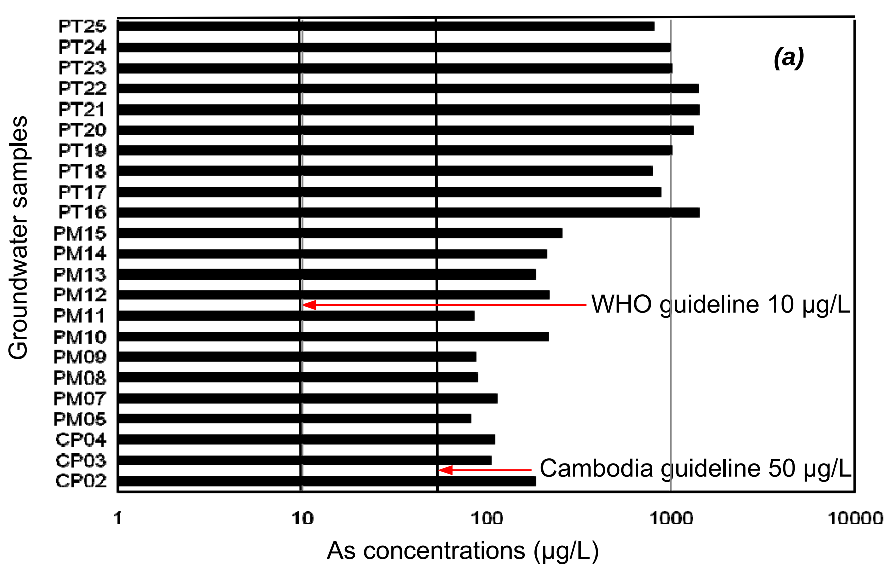
Table 1. Characteristics of groundwater in CP, PM and PT villages of the Kandal Province, Cambodia *(a)* in summary and *(b)* in details

(a)

Parameter	Unit	CP village			PM village			PT village		
		Average	Median	Range	Average	Median	Range	Average	Median	Range
pH		6.94	6.93	6.81-7.09	7.15	7.16	6.98-7.28	7.48	7.45	7.38-7.62
tº	ºC	29.2	29.2	28.1-30.2	28.8	28.9	27.9-29.3	28.9	29.0	28.2-29.2
EC	mS/m	121.0	86.6	51.7-259	61.8	59.7	42.7-88.3	49.9	50.7	46.8-52.2
Eh	mV	+97	+79	68-160	+57	+57	34-70	+36	+35	27-46
As	mg/L	0.132	0.111	0.106-0.181	0.153	0.148	0.085-0.25	1.103	1.02	0.782-1.42
Fe	mg/L	3.798	4.25	0.842-5.84	4.413	4.42	3.31-5.36	1.556	1.565	0.704-2.58
F^-	mg/L	0.285	0.108	0.025-0.910	0.097	0.104	0.04-0.126	0.189	0.188	0.056-0.326
Cl^-	mg/L	105.87	74.827	17.33-256	44.53	26.273	5.7-111.64	2.881	2.777	2.22-4.543
NO_2^-	mg/L	0.0053	0.0053	0.001-0.008	0.0046	0.0036	0.001-0.01	0.326	0.0238	0.019-0.053
Br^-	mg/L	0.506	0.182	0.065-1.596	0.147	0.0883	0.03-0.405	0.0238	0.0241	0.02-0.0287
NO_3^-	mg/L	2.171	0.067	0.020-8.531	0.2008	0.0684	0.009-0.69	0.1491	0.0413	0.0075-0.75
PO_4^{3-}	mg/L	0.791	0.791	0.743-0.84	0.3021	0.135	0.003-0.93	0.3348	0.2835	0.103-0.625
SO_4^{2-}	mg/L	7.239	6.517	0.081-15.84	0.0951	0.0934	0.065-0.15	0.0544	0.0532	0.041-0.067

(b)

Sample	pH	t° (°C)	EC (mS/m)	Eh (mV)	As (µg/L)	Fe (µg/L)	F^- (µg/L)	Cl^- (µg/L)	NO_2^- (µg/L)	Br^- (µg/L)	NO_3^- (µg/L)	PO_4^{3-} (µg/L)	SO_4^{2-} (µg/L)
CP01	6.95	29.0	259	+160	-	842	901	256509	-	1596	8531	-	15841
CP02	6.81	29.5	62.7	+83	181	5840	158	30275	1.78	120	33.95	743	81.31
CP03	7.09	30.2	110.6	+76	106	4180	59	119379	-	244	100.04	-	12455
CP04	6.92	28.1	51.7	+69	111	4330	25	17331	8.84	65.32	20.10	839	579.03
PM05	6.98	28.3	49.4	+70	80.9	3730	80	20643	3.62	71.21	37.59	135	93.47
PM06	7.00	27.9	42.7	+69	-	4360	102	5688	10.07	30.39	68.47	934	88.31
PM07	7.07	28.7	47.0	+61	113	4720	104	11898	7.38	51.51	33.26	279	94.42
PM08	7.16	29.1	59.7	+58	88	5360	121	52571	1.13	144.72	690.07	39	148.67
PM09	7.23	28.9	65.4	+56	86.5	3680	-	-	-	-	-	-	-
PM10	7.28	28.9	52.5	+34	216	3310	42	26273	3.57	88.36	8.82	928	64.93
PM11	7.12	29.1	48.1	+62	84.6	5070	126	19109	5.10	63.05	19.14	106	68.49
PM12	7.26	29.3	80.0	+55	217	4420	-	-	-	-	-	-	-
PM13	7.17	29.3	84.5	+53	183	4910	111	101108	-	404.93	365.01	139	91.41
PM14	7.18	28.9	88.3	+54	209	4240	85	111636	-	359.73	200.44	35	98.87
PM15	7.16	29.3	62.3	+57	254	4750	108	51856	1.76	112.09	384.60	124	107.25
PT16	7.44	28.2	48.2	+46	1410	1400	192	2220	21.62	18.92	13.18	186	41.65
PT17	7.48	29.0	51.7	+29	884	1890	326	2777	22.48	24.11	33.12	233	53.20
PT18	7.53	28.9	50.5	+44	782	937	305	3064	45.22	21.98	753.70	-	-
PT19	7.45	28.6	46.8	+35	1020	1980	188	2254	38.83	25.85	7.52	134	49.63
PT20	7.62	29.0	49.3	+36	1310	704	104	2314	23.79	19.90	198.64	334	49.83
PT21	7.39	29.2	50.9	+27	1420	1650	-	-	-	-	-	-	-
PT22	7.46	29.1	52.2	+40	1400	1480	56	4543	19.75	28.74	124.55	597	66.71
PT23	7.44	29.2	50.9	+31	1020	1670	149	2840	21.69	-	49.55	467	60.86
PT24	7.38	29.1	46.8	+34	991	2580	124	2303	47.37	-	12.47	103	-
PT25	7.58	29.1	51.5	+35	799	1270	260	3618	52.89	27.19	-	625	59.39



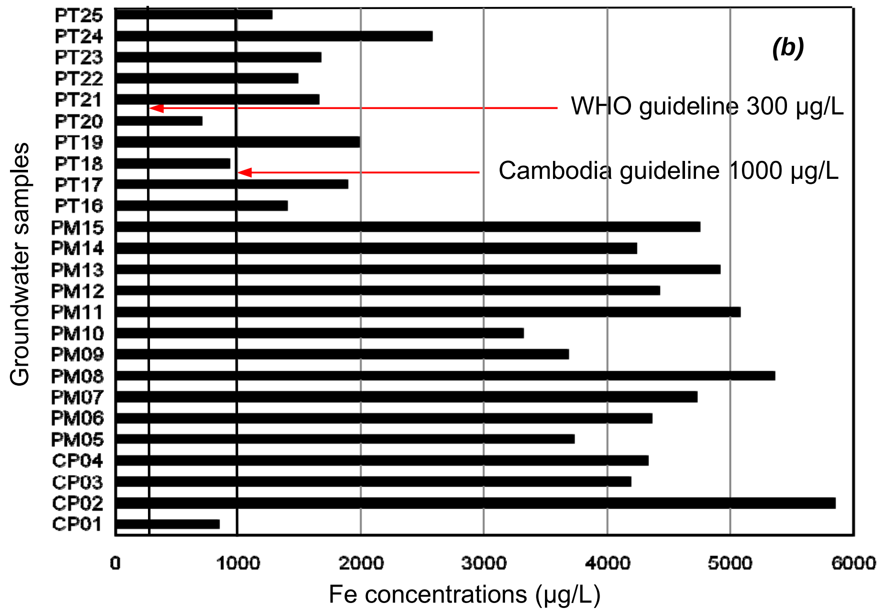


Figure 2. Arsenic *(a)* and iron *(b)* concentrations in the groundwater of the CP, PM and PT villages of the Kandal Province, Cambodia