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Arsenic and Other Metal Contamination of Groundwater in the Mekong River Delta, Vietnam

Yasuhiro Shinkai,^{*a*} Duong Van Truc,^{*b*} Daigo Sumi,^{*a*} Doan Canh,^{*b*} and Yoshito Kumagai^{*,*a*}

^aDepartment of Environmental Medicine, Doctoral Programs in Medical Sciences, Graduate School of Comprehensive Human Sciences, University of Tsukuba, 1–1–1 Tenno-dai, Tsukuba, Ibaraki 305–8575, Japan and ^bDepartment of Environmental Management and Technology, Institute of Tropical Biology, 85 Tran Quoc Toan, Dist. 3, Ho Chi Minh, Vietnam

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High levels of arsenic (As) contamination are found in the groundwater of Vietnam. To determine the distribution of arsenic and other metal contamination in the groundwater of the Mekong River Delta, we examined the contamination status of As and other metals in two regions, Tien Giang Province and Dong Thap Province. The concentration of total As in the groundwater, which is used for the drinking water supply, ranged from $0.9 \,\mu$ g/l to $321 \,\mu$ g/l, and 27%of the shallow-well water samples exceeded the World Health Organization (WHO) provisional guideline of 10 µg/l. Also, 91% and 27% of shallow-well water samples had higher concentrations of manganese (Mn) and barium (Ba) than those stated in the WHO drinking water guidelines, respectively. On the other hand, such contamination was not found in the deepwell water samples examined. These results suggest that pollution by As, Mn, and Ba is widely distributed in the shallow aquifer of the Mekong River Delta and thus the health of the people consuming shallow-well water in both provinces might be at considerable risk.

Key words —— arsenic, manganese, barium, groundwater, Mekong River Delta, Vietnam

INTRODUCTION

Arsenic (As) is a toxic metalloid that causes adverse effects on human health.^{1,2)} Natural contamination of groundwater by As has become a critical water quality problem in many parts of the world, particularly in east Asia.³⁾ In Vietnam, the population at risk of chronic As poisoning is estimated to be 10 million in the Red River Delta and 0.5–1 million in the Mekong River Delta.⁴⁾

Berg et al. found concentrations of As in the groundwater of the Red River Delta that were higher than the World Health Organization (WHO) drinking water guideline of $10 \mu g/l$, and the levels are comparable to those in Bangladesh and West Bengal, India.⁵⁾ Also, Agusa et al. showed that concentrations of manganese (Mn) and barium (Ba) as well as of As were above the WHO drinking water guidelines in some groundwater of the Red River Delta,⁶⁾ indicating the need for research on contamination of multiple elements in groundwater. In regard to the Mekong River Delta, Stanger et al. recently reported on As pollution in groundwater collected from the lower Mekong basin.⁷⁾ To our knowledge, however, a study of contamination by multiple elements in the Mekong River Delta has not been reported.

In the present study, we evaluated the contamination status of As and other metals in groundwater pumped from shallow and deep wells in two areas of the Mekong River Delta, Tien Giang Province and Dong Thap Province. In addition, the relation between As and other metals was examined.

MATERIALS AND METHODS

Sample Collection — Figure 1 shows the sampling locations for raw groundwater in Vietnam. We randomly collected from 14 wells in Tien Giang Province and Dong Thap Province, located in the Mekong River Delta and about 90 km and 250 km from Ho Chi Minh City, respectively. Groundwater samples from the wells were collected in July (rainy season) 2006. Prior to sampling, the tube wells were flushed with a moderate amount of groundwater. The samples were transported to the laboratory and kept refrigerated (4°C) until analysis.

Water Analysis — Water pH was measured with a glass electrode pH meter (DKK TOA Corporation) (Tokyo, Japan). After the water samples were filtered ($0.45 \mu m$), concentrations of Ca, Cd, Cr,

^{*}To whom correspondence should be addressed: Department of Environmental Medicine, Doctoral Programs in Medical Sciences, Graduate School of Comprehensive Human Sciences, University of Tsukuba, 1–1–1 Tenno-dai, Tsukuba, Ibaraki 305–8575, Japan. Tel.: +81-29-853-3133; Fax: +81-29-853-3133; E-mail: yk-em-tu@md.tsukuba.ac.jp

Cu, Fe, Mg, Mn, Ni, P, As, Se, Ba, and Pb were determined using an inductively coupled plasmaatomic emission spectrometer (ICP-AES) 61E-trace (Thermo Jarrell Ash). If the As concentration was below the detection limit of the ICP-AES, the water samples were analyzed using an inductively coupled plasma mass spectrometer (ICP-MS) HP4500 model (Agilent Technologies).

Statistical Analysis —— Student's *t*-tests were performed between the different groups, and differences with two-sided *p* values of less than 0.05 were regarded as statistically significant.

RESULTS AND DISCUSSION

As shown in Fig. 2, As was detected in all the groundwater samples, and their levels were from $0.9 \,\mu\text{g/l}$ to $8.8 \,\mu\text{g/l}$ in Tien Giang Province and from $1.6 \,\mu\text{g/l}$ to $321 \,\mu\text{g/l}$ in Dong Thap Province. Some samples (3/14) had As concentrations over the WHO drinking water guideline ($10 \,\mu\text{g/l}$). In addition, in some samples, concentrations over the WHO drinking water guideline were found for Mn ($0.4 \,\text{mg/l}$, 10/14) and Ba ($0.7 \,\text{mg/l}$, 3/14) (Fig. 3). These findings indicate that residents living in the



Fig. 1. Map of the Study Area (Mekong River Delta, Vietnam) The numbers correspond to the examined groundwater wells, which are used for the drinking water supply.



Fig. 2. Concentration of As and pH Value in the Groundwater The bars and circles indicate As concentration and pH value, respectively. The dotted line shows the WHO drinking water guideline.





 Table 1. Comparison of Concentrations of Calcium, Magnesium, Mn, and Ba between the Deepand Shallow-well Water Groups

Well group (<i>n</i>)	Ca	Mg	Mn	Ba
Deep (3)	17.7 ± 9.0	6.6 ± 3.4	0.0 ± 0.0	0.2 ± 0.1
Shallow (11)	$81.4 \pm 30.2^{*}$	$63.7 \pm 28.1^*$	$2.8 \pm 2.9^*$	$0.8 \pm 0.9^{**}$

Values shown are mean \pm S.D. (mg/l). Significantly different from the deep-well group: *p < 0.01, **p < 0.05.

Mekong River Delta may be exposed not only to As but also to Mn and Ba from groundwater, and the possible adverse health effects are a matter of concern. Contamination by As, Mn, and Ba in groundwater has been reported in other areas of Vietnam,⁶⁾ indicating that contamination by As, Mn, and Ba is widely distributed in that country. On the other hand, a high concentration of other harmful metals such as Cd, Cr, Cu, Ni, Se, and Pb was not seen in any of the water samples (data not shown).

The presence of As in groundwater is believed to be of geologic origin associated with the depth of wells. In this study, some samples (3/14) were collected from deep wells with a depth of over 300 m, and other samples (11/14) were collected from shallow wells with a depth of about 30 to 60 m. In general, a high concentration of As has been observed in shallow aquifers.⁷⁻⁹⁾ Consistent with this, some samples collected from shallow wells were contaminated with a high concentration of As, whereas samples collected from deep wells were not. In addition, the average number of shallow-well groups had significantly higher concentrations of Mn, Ba, Ca, and Mg than those of the deep-well groups (Table 1). These results suggest that shallow-well waters in the Mekong River Delta are hard water and unsafe in comparison with its deep-well waters.

It has been shown that the As concentration is positively correlated with the concentration of Fe,^{5,6)} Ba,⁶⁾ P,¹⁰⁾ and/or pH value.¹⁰⁾ In this study, high concentrations of As and Ba were found in the same well water, suggesting that Ba contamination may be associated with As contamination in the Mekong River Delta. However, the concentrations of Fe, P (data not shown), and pH value in the examined water were not found to correlate. The reasons for these relationships are not known, but may be related to geochemical properties in the subsurface of the Mekong River Delta. Further epidemiologic investigation is required for evaluation of the potential health effects of As, Mn, and/or Ba exposure on the residents living in the Mekong River Delta, Vietnam.

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