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Health risk assessment of inorganic arsenic intake of Cambodia residents through groundwater drinking pathway

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ABSTRACT

In order to compare the magnitudes and health impacts of arsenic and other toxic trace elements in well water, groundwater and hair samples were collected from three areas with different arsenic exposure scenarios in the Mekong River basin of Cambodia. Ampil commune in Kampong Cham province was selected as an uncontaminated area, Khsarch Andaet commune in Kratie province was selected as a moderately contaminated area, and Kampong Kong commune in Kandal Province was selected as an extremely contaminated area. Results of ICP-MS analyses of the groundwater samples revealed that As, Mn, Fe and Ba concentrations were significantly different among the three study areas (Kruskal–Wallis test, $p < 0.0001$). Out of 46 observed wells in the Kandal province study area, 100% detected As > 50 μg L^{-1} and Fe > 300 μg L^{-1}; 52.17% had Mn > 400 μg L^{-1} and 73.91% found Ba > 700 μg L^{-1}. In the Kratie province study area ($n = 12$), 25% of wells showed elevated arsenic levels above 10 μg L^{-1} and 25% had Mn > 400 μg L^{-1}, whereas samples from Kampong Cham province study area ($n = 18$) were relatively clean, with As < 10 μg L^{-1}. A health risk assessment model derived from the USEPA was applied to calculate individual risks resulting from drinking groundwater. Computational results indicated that residents from Kandal Province study area ($n = 297$) confronted significantly higher non-carcinogenic and carcinogenic risks than those in Kratie ($n = 89$) and Kampong Cham ($n = 184$) province study areas (Kruskal–Wallis test, $p < 0.0001$). 98.65% of respondents from the Kandal province study area were at risk for the potential non-cancer effect and an average cancer risk index was found to be 5 in 1000 exposure. The calculations also indicated that, in the Kratie province study area, 13.48% of respondents were affected by non-cancer health risks and 33.71% were threatened by cancer, whereas none of respondents in the Kampong Cham province study area appeared to have non-carcinogenic effect. Positively significant correlations of the arsenic content in scalp hair (As_h) with both arsenic levels in

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groundwater (As_w) (r_s (304) = 0.757, $p < 0.0001$) and individual average daily doses (ADD) of arsenic (r_s (304) = 0.763, $p < 0.0001$) undoubtedly indicated that arsenic accumulation in the bodies of Cambodia residents in the Mekong River basin was mainly through a groundwater drinking pathway. To the best of our knowledge, this is the first comprehensive report comparing individual health risk assessments of arsenic exposure through a groundwater drinking pathway to enriched arsenic levels from groundwater in the Mekong River basin, Cambodia. This study indicates that elevated arsenic concentrations in groundwater may lead to thousands of cases of arsenicosis in the near future if mitigating actions are not taken.

1. Introduction

The widespread switch from microbiologically-unsafe surface water to microbiologically-unsafe groundwater has led to the unanticipated poisoning of large numbers of people in the developing world who have consumed various toxic trace elements. In particular, elevated concentrations of arsenic in groundwater have been reported in Taiwan (Tseng, 1977; Tseng et al., 1968), West Bengal (India) and Bangladesh (Das et al., 1994; Mandal et al., 1998; Nickson et al., 1998), resulting in a major public health issue. In Bangladesh and West Bengal (India), it is estimated that approximately 40 million people are suffering from drinking naturally occurring arsenic-rich shallow groundwater (Gault et al., 2008). Despite these concerns, groundwater is still a major source of drinking water in the developing world, especially in Southeast Asia. Recently, unsafe levels of arsenic have also been revealed in Vietnam (Berg et al., 2007, 2001; Buschmann et al., 2007; Nguyen et al., 2009) and Cambodia (JICA, 1999; Polya et al., 2003, 2005).

Individuals can be exposed to arsenic through several pathways, but the most critical one is daily diet and drinking water ingestion. Toxicological studies show that both trivalent and pentavalent soluble arsenic compounds are rapidly absorbed from the gastrointestinal tract and can be further metabolized. Reduction of As (V) to As (III) followed by oxidative methylation of As (III) takes place to form mono-, di- or trimethylated products (Hughes, 2002). Oral pathway exposure of organic arsenic compounds is less toxic since organic arsenicals are less extensively metabolized and more rapidly eliminated in urine than inorganic arsenicals (WHO, 2004; ATSDR, 2007). There is no evidence that arsenic is essential in human bodies. In contrast, chronic oral consumption of arsenic is considered to cause an adverse impact on human beings, known as “arsenicosis” or “arsenic poisoning disease”. Arsenicosis can cause skin lesions, pigmentation of the skin, and the development of hard patches of skin on the palm of the hands and soles of the feet. Arsenic poisoning finally leads to skin, bladder, kidney, and lung cancers, as well as diseases of the blood vessels of the legs and feet. Diabetes, high blood pressure and reproductive disorders may also be the side effects of chronic arsenic exposure (Tseng, 1977; WHO, 2004; ATSDR, 2007).

In Cambodia, unsafe levels of arsenic in shallow groundwater were first reported by JICA (1999) in its first unpublished draft report, named “The study on groundwater development in Southern Cambodia”, to the Cambodia Ministry of Rural Development. Consequently, numerous studies have been conducted and documented. Polya et al. (2003, 2005); Stanger et al. (2005); Berg et al. (2007); Buschmann et al. (2007); Quicksall et al. (2008); Sthiannopkao et al. (2008) & Luu et al. (2009) have described the distribution of arsenic in shallow Cambodian groundwater. The chemical, biological and physical processes that control the heterogeneous arsenic distribution in groundwater have also been widely studied (Polya et al., 2003, 2005; Rowland et al., 2008; Lear et al., 2007; Berg et al., 2007; Buschmann et al., 2007; Benner et al., 2008; Kocar et al., 2008; Polizzotto et al., 2008, Robinson et al., 2009). Arsenic treatment systems, modified from traditional sand filters, have also been developed to enhance arsenic removal from groundwater following seasonal and spatial variations in groundwater composition (Chiew et al., 2009).

In addition, studies of baseline concentrations of As in human hairs, nails and urine have been used to assess potential biomarkers of As exposure (Kubota et al., 2006; Berg et al., 2007; Gault et al., 2008; Sampson et al., 2008). The development of visual arsenicosis symptoms have been generally assumed to follow 8–10 years of consumption of water with unsafe level of arsenic; however, new cases discovered in Cambodia have followed exposure times as short as three years, due to extremely elevated arsenic levels (3500 $\mu g\ L^{-1}$), socioeconomic status, and malnutrition (Sampson et al., 2008). In Kandal alone, by using groundwater quality and population data, Sampson et al. (2008) have estimated that 100,000 people are at high risk of chronic arsenic exposure.

The objectives of the present study were (i) to determine the distribution of toxic trace elements in groundwater of the Mekong River basin of Cambodia, (ii) to determine the heterogeneous distribution of arsenic species in groundwater, (iii) to assess non-carcinogenic and carcinogenic risks among the populations exposed to arsenic through groundwater drinking pathways, (iv) to correlate the arsenic content in scalp hair (As_h) with arsenic levels in groundwater (As_w) and individual average daily doses (ADD) of arsenic, and (v) to compare the extent of health impacts with respect to different levels of arsenic-rich groundwater.

2. Materials and methods

2.1. Study area

The design of the present study was a cross-sectional study. Sampling was carried out within three purposely selected