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Arsenic and other elements in drinking water and dietary components from the middle Gangetic plain of Bihar, India: Health risk index

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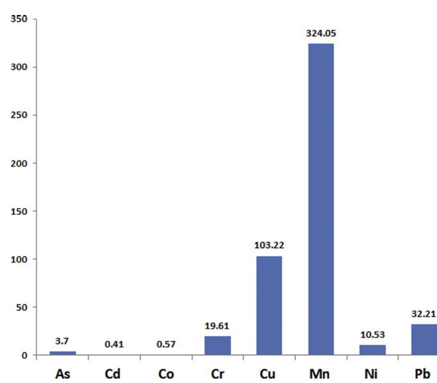
HIGHLIGHTS

- Concentrations of As and other elements in water and dietary components
- Comparative analysis of concentration of As in uncooked and cooked rice
- Daily intake of As and other elements via water and dietary components
- Estimation of potential health hazards by comparing JECFA values of metals
- Estimation of chronic daily intake and health risk index

GRAPHICAL ABSTRACT



Estimated exposure of elements (μg per kg bw) from drinking water and food components in Samastipur, Bihar, India

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ABSTRACT

This study investigates the level of contamination and health risk assessment for arsenic (As) and other elements in drinking water, vegetables and other food components in two blocks (Mohiuddinagar and Mohanpur) from the Samastipur district, Bihar, India. Groundwater (80%) samples exceeded the World Health Organization (WHO) guideline value (10 μg/L) of As while Mn exceeded the previous WHO limit of 400 μg/L in 28% samples. The estimated daily intake of As, Cd, Co, Cr, Cu, Mn, Ni, Pb and Zn from drinking water and food components were 169, 19, 26, 882, 4645, 14582, 474, 1449 and 12,955 μg, respectively (estimated exposure 3.70, 0.41, 0.57, 19.61, 103.22, 324.05, 10.53, 32.21 and 287.90 μg per kg bw, respectively). Twelve of 15 cooked rice contained high As concentration compared to uncooked rice. Water contributes (67%) considerable As to daily exposure followed by rice and vegetables. Whereas food is the major contributor of other elements to the dietary exposure. Correlation and principal component analysis (PCA) indicated natural source for As but for other elements, presence of diffused anthropogenic activities were responsible. The chronic daily intake (CDI) and health risk index (HRI) were also estimated from the generated data. The HRI were >1 for As in drinking water, vegetables and rice, for Mn in drinking water, vegetables, rice and wheat, for Pb in rice and wheat indicated the potential health risk to the local population.

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An assessment of As and other elements of other food components should be conducted to understand the actual health hazards caused by ingestion of food in people residing in the middle Gangetic plain.

1. Introduction

Contamination of groundwater through naturally occurring arsenic (As) has been reported in many countries around the world, particularly in Southeast Asia causing serious threat to humans (Mandal and Suzuki, 2002; Mukherjee et al., 2006; Naidu et al., 2006). This has received significant attention in the last three decades due to its serious health effects on millions of people and has been termed "the biggest As calamity in the world" (Smith et al., 2000). Arsenic contamination of tubewells in the middle Gangetic plain was first reported in 2002 in Semria Ojha Patti village (area 4 km^2), Sahapur block in the Bhojpur district of Bihar, India (Chakraborti et al., 2003). About 89% geographical area of Bihar (~94,000 km^2), India is located in the middle Gangetic plain and is known for surplus food production and intensive groundwater extraction for drinking and irrigation (Saha, 2009). It was reported that 57 blocks in 15 districts of Bihar are As-affected (Saha, 2009). Arsenic in low concentration can stimulate plant growth but in higher concentration it can be accumulated above the WHO threshold concentrations for safe ingestion of food crops (Rahman and Naidu, 2009). As a consequence, food crops accumulate elevated As which pose serious risks to the health of local residing population (Dudka and Miller, 1999). Therefore, it is crucial to assess As exposure via commonly used food grains such as wheat, rice, maize and green gram. High concentrations of As in tubewell water and sediments of the middle Gangetic plain have been documented (Chauhan et al., 2009; Kumar et al., 2010a,b; Saha, 2009; Saha et al., 2010a,b; Shah, 2013). The As concentration >50 μg/L has been reported in Samastipur district, Bihar (Saha and Shukla, 2013). Significant As concentration was reported in hair, average values 5500 μg/kg (range: 4000–8800 μg/kg) and 14,200 μg/kg (range: 6100–24,000 μg/kg) in nails of people living in Maner district of Bihar, India (Sanz et al., 2007). In another study from Maner, Bihar, As concentrations have been reported in wheat, maize, rice-grain, and lentil to be 24, 11, 19 and 15 μg/kg, respectively (Singh and Ghosh, 2011).

Arsenic is a toxic element, known as class (I) human carcinogen and widely distributed in the environment as both inorganic and organic forms (Hughes et al., 2011). In general, the inorganic forms (arsenite and arsenate) of As are much more toxic than the organic forms (monomethylarsonic acid, dimethylarsinic acid, arsenobetaine etc.) of As. Arsenite is generally more toxic than arsenate and humans are exposed to both forms of inorganic As from water and food. There are many pathways by which As can enter the human body via food chain (ingestion by water and food sources) and occupational exposure are the most common (Rahman et al., 2009). Various inorganic species (arsenite and arsenate) and organic species (methylated anionic species, volatile As hydride and organo-As) in food materials have been reported as the main pathways to human exposure (Momplaisir et al., 2001). From a health perspective, it is equally important to study the trace elements other than As present in water and in dietary food components. The concentration of other toxins in drinking water and dietary food materials may cause synergistic effects. For instance, deficiency of beneficial elements such as selenium (Se) and zinc (Zn) may increase As toxicity (Frisbie et al., 2002). A study has concluded that groundwater of Bangladesh is unsafe because tubewell waters exceeded the WHO guidelines for As, lead (Pb), manganese (Mn) nickel (Ni), chromium (Cr), molybdenum (Mo), uranium (U), boron (B), and barium (Ba) (Frisbie et al., 2002). The same conditions have also been suspected in the densely populated areas of the middle Gangetic plain due to the geological similarities in alluvial and deltaic plains (Frisbie et al., 2002).

Several attempts have been made to investigate the concentration of As in groundwater, health effect due to As toxicity and the mechanism of mobilization process of As in the middle Ganga plain of Bihar (Chakraborti et al., 2003; Chauhan et al., 2009; Kumar et al., 2010b; Kumar et al., 2015; Saha, 2009). Arsenic above 50 μg/L was detected in 47% of tubewells in Bhagalpur, Bihar (Kumar et al., 2010b), while it was 58.6% in Semaria Ojha Patti, Bihar, India (Chakraborti et al., 2003). A range of 6–389.4 μg/L of As was also observed in Samastipur, India (Saha and Shukla, 2013). Very limited efforts have been directed to determine the degree of As contamination in food components and the associated risk to human through consumption of food. No study has reported elemental concentrations in commonly consumed food components from the middle Ganga plain of Bihar. It is therefore timely to determine the level of As and other toxic elements present in water, vegetables and other food components grown in this particular area. The total exposure to As and other elements in water, vegetables and other dietary components in the Samastipur district of Bihar, India was the main focus of this study. An attempt was also made to understand the potential health risk due to consumption of contaminated water and food components and the role of other elements because they may have synergetic effect on people living in the study area.

2. Material and methods

2.1. Study area description, sample collection and preparation

Samastipur district, Bihar which is situated in the eastern part of the Gangetic plain, is characterized by a monotonous flat alluvial landform known as the North Ganges plain (Saha et al., 2010b). Fig. 1 shows the location of the study area in Bihar, India (middle Gangetic plain) and the corresponding sampling points. Hand-pumps and tubewells are mainly logged in shallow aquifers (20–60 m) only. Irrigation undertaken in this area relies on the shallow aquifers (Saha and Shukla, 2013). Tubewell water samples ($n = 23$), wheat ($n = 35$), uncooked rice ($n = 15$), cooked rice ($n = 15$), maize ($n = 31$) and vegetables ($n = 34$), commonly consumed by residents of this area, were collected from two blocks (Mohiuddinagar and Mohanpur) of Samastipur district, Bihar, India in May 2013. According to Census of India 2011, the total area of Mohiuddinagar block is 129.54 km^2 (population 184,521); while the area of Mohanpur is 81.02 km^2 (population 115,032). Rice (both uncooked and cooked rice), wheat, maize and green gram samples were collected from households. All surveyed families revealed that collected samples were grown locally in their respective agricultural fields. In the study area, rice was cooked using excess water (ratio is 1:2), excess water was removed after cooking. Tubewell water was used for rice cooking by surveyed families. Vegetables were collected from the nearby gardens of each surveyed household. The local, English and botanical names of the vegetables and other dietary components collected are provided in Table 1. Water samples were collected in pre-cleaned (washed with concentrated nitric acid followed by Milli-Q water) polypropylene bottles followed by acidification. After collection, the food samples were stored in cool box and then store at 4 °C upon return to the laboratory. Before processing, all food samples were kept at room temperature for several hours. Food samples process method was reported elsewhere (Rahman et al., 2013). Briefly, all food samples except cooked rice were washed three times with tap water followed by de-ionized water (twice). All food samples were dried in an oven at 65 °C and homogenized by grinding with a stainless steel grinder. Each sample was then stored in a separate plastic zip-lock bag. All