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Levels of arsenic pollution in daily foodstuffs and soils and its associated human health risk in a town in Jiangsu Province, China

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ABSTRACT

The development of industries in rural areas can aggravate the arsenic (As) contamination of the local environment, which may pose unacceptable health risks to the local residents. This paper estimated the health risk posed by inorganic As (iAs) to residents via ingestion of soil, skin contact with soil and consumption of foodstuffs in a typical rural- industrial developed town in southern Jiangsu, China. The average concentrations of total As in soil, rice, fish, shrimp and crab, pork and eggs, vegetables and fruits were detected to be 10.367, 0.104 mg/kg dw (dry weight), 0.050, 0.415, 0.011, 0.013 and 0.017 mg/kg fw (fresh weight), respectively. All of these values are below the maximum allowable concentration in food and soil in China. The deterministic estimation results showed that the hazard quotient (HQ) and excess lifetime cancer risk (*R*) were 1.28 (0.78–2.31) and 2.38×10^{-4} (2.71×10^{-5}–5.09×10^{-4}) for all age groups, respectively. Males in the age range of 2–29 years and females in the age range of 2–13 years and 18–29 years exhibited non-carcinogenic risk (HQ > 1). Carcinogenic risk exceeded the acceptable level of 1×10^{-5} for both genders at all ages. Furthermore, this risk rose with age. The probabilistic estimation results showed that about 28% of residents had non-carcinogenic risk due to over ingestion of iAs. The *R* value of 90% of residents was greater than 10^{-5}. The sensitivity analysis indicated that the cancer slope factor (SF), the ingestion rates of rice and the iAs concentration in rice were the most relevant variables affecting the assessment outcome. Based on these results, it is recommended that residents reduce their consumption of rice, though it should be noted that the assessment outcome has uncertainty due to estimating iAs from foodstuffs and not considering the bioaccessibility of iAs in foodstuffs. Nevertheless, measures like reducing industrial As emissions, forbidding the use of pesticides, fertilizers and sludge which contain As and optimizing water management in rice paddy fields should be taken to mitigate the risks.

1. Introduction

Arsenic (As) widely exists in water, sediment and soil and may enter the human body mainly through food and drink. Arsenic originates from both natural and anthropogenic sources. Copper smelting and coal combustion are two major sources, accounting for 60% of total anthropogenic As emission (Matschullat, 2000). The global annual anthropogenic input of As into the soil was estimated to be between 2.84×10^7 and 9.4×10^7 kg/year, approximately 41% of which is derived from waste from commercial products, 23% from coal ash, 14% from atmospheric deposition, 10% from tailings materials, 7% from smelters, 3% from agriculture and 2% from industrial production and other minor sources (Chilvers and Peterson, 1987; Nriagu and Pacyna, 1988). Arsenic pollution is a very serious environmental problem worldwide, and the contamination of soils and water by As and its associated health risk have been reported in many countries (Ohno et al., 2007; Roychowdhury, 2010; Cheng et al., 2010; Fujino et al., 2004; Liu et al., 2009; Hanh et al., 2011).

Once As enters the body, regardless of the route, most of it will accumulate in the body, with the exception of a small amount that is eliminated. Arsenic is deposited mainly in the hair, nails, bones and organs, such as the liver and kidneys (World Health Organization (WHO), 2001). Arsenic can damage the REDOX abilities of cells; affect the normal metabolism of cells; cause tissue damage and disorders in the body; damage the nervous system; digestive system and cardiovascular system; and even directly cause death

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(Rahman et al., 2009). Acute exposure to As can lead to nausea, diarrhea, encephalopathy, and neuropathy (Ramirez-Andreotta et al., 2013). Chronic low-level As exposure has been associated with diabetes and hypopigmentation/hyperkeratosis and may likely promote cancer of the bladder, lung, skin and prostate (WHO, 2010; Soghoian and Sinert, 2009; Tchounwou et al., 2004). Many recent studies have focused on the chronic low-level exposure to arsenic (Liao et al., 2008; Rahman et al., 2008; Wu et al., 2014). This element is considered the top contaminant of concern by the Agency for Toxic Substances and Disease Registry of the United States of America (USA) (ATSDR–Agency for Toxic Substances and Disease Registry, 2011) because of the frequency at which it is found, its toxicity and its potential for human exposure.

Jiangsu Province in China is highly economically developed, and the machinery, electronics, petrochemical and automobile industries are its pillar industries. The local environment has been polluted due to an unreasonable development structure and aggressive business model. In recent years, many studies on the pollution status of southern Jiangsu Province have been conducted. The agricultural soil in the region has been polluted to some extent by multiple heavy metals. Pollution by cadmium (Cd), lead (Pb) and As has been particularly serious (An et al., 2005). According to a survey of heavy metal pollution in the soil used for vegetable cultivation in Jiangsu, the As content in some cultivation areas has reached 56.93 mg/kg, which is greater than the Class II standard for soil environmental quality (Wang and Cao, 2002). Measurements of Cd, As, Pb, mercury (Hg), copper (Cu), zinc (Zn), chromium (Cr) and nickel (Ni) in farmland and 17 agricultural products of the Taihu Lake region showed that the average contents of heavy metals were all higher than those observed in studies conducted six years prior (Liu et al., 2006). Similar to other provinces with developed rural-industries in the coastal region, local residents in the township in Jiangsu are exposed to pollutants like heavy metals from agricultural, industrial and domestic sources. They inhale polluted air, come into contact with contaminated soil, and consume crops and aquatic food products from contaminated local fields or ponds. It is necessary to explore the health risk associated with exposure to pollutants from these multiple sources.

A typical rural-industrial town in southern Jiangsu was selected for this study. We investigated the status of As pollution in farmland soil and local foodstuffs, estimated the exposure of residents to inorganic As (iAs) via the ingestion of foods and soils and dermal contact with soil, evaluated the health risk of local residents exposed to iAs, and finally analyzed factors that had a crucial influence on residents' health risk.

2. Materials and methods

2.1. Study site and sampling

The studied town X in southern Jiangsu is economically developed (see our previous study (Cao et al., 2010) for the site map). More than 500 rural enterprises are located in the town, which are primarily comprised of electroplating, chemical processing, dyeing, pigment making and metal processing facilities. Rice is the major crop and is eaten as a staple food by local residents at every meal. Many families cultivate vegetables in their yards or on nearby spare lands for their own consumption. Aquatic products are also consumed, and many pools are dug in fields to cultivate shrimp, crab or fish. The residents' daily food is both self-cultivated and purchased from markets. Tap water is used for drinking and cooking.

Rice, garden vegetables, cultivated soil and aquatic food products were sampled four times in May and September 2008 and 2009. The sampling sites were randomly distributed. A total of 458 agricultural products and 143 soil samples were collected. Most of the food samples were self-cultivated by the inhabitants. Some were bought from the market to reflect the actual exposure scenario. The vegetable samples included 17 species which were representative of the species cultivated for personal consumption in the studied area. All of the food samples were divided into 10 categories: rice, fish, shrimp and crabs, pork and eggs, leafy vegetables, gourd vegetables, solanaceous vegetables, root vegetables, beans and fruits (Table 1).

Table 1
Total As contents in different categories of food (mg/kg, dry weight for rice and fresh weight for others).

Food category	*N*	Mean (minimum-maximum)	Limit [a]
Rice	39	0.104 (0.046–0.247)	0.2 [b]
Fish	27	0.050 (0.025–0.074)	0.1 [b]
Shrimps and crabs	18	0.415 (0.194–0.657)	0.5 [b]
Shrimps	10	0.332 (0.194–0.482)	
Crabs	8	0.519 (0.393–0.657)	
Pork and eggs	28	0.011 (0.001–0.035)	0.5
Pork	20	0.012 (0.002–0.035)	
Eggs	8	0.007 (0.001–0.020)	
Leafy vegetables	112	0.023 (0.002–0.116)	0.5
Brassica pekinensis (Lour.) Rupr./Chinese cabbage	16	0.019 (0.006–0.054)	
Brassica chinensis Linn./green cabbage	11	0.021 (0.010–0.032)	
Allium tuberosum Rottl. ex Spreng./leek	22	0.015 (0.006–0.037)	
Ipomoea aquatica Forssk./swamp morningglory	28	0.035 (0.015–0.116)	
Lactuca sativa L. var. romana Hort/lettuce	25	0.013(0.002–0.032)	
Amaranthus mangostanus L./edible amaranth	10	0.036 (0.021–0.054)	
Gourd vegetables	61	0.010 (0.001–0.060)	0.5
Luffa cylindrical (L.) Roem/towel gourd	31	0.009 (0.001–0.060)	
Cucumis sativus L./cucumber	23	0.013 (0.004–0.060)	
Benincasa hispida (Thunb.) Cogn./Chinese wax gourd	7	0.004 (0.003–0.006)	
Solanaceous vegetables	78	0.006(0.001–0.022)	0.5
Capsicum annuum L. var.grossum (L.) sendt/capsicum	29	0.005(0.001–0.010)	
Solanum melongena/eggplant	40	0.007(0.002–0.013)	
Lycopersicon esculentum Mill./tomato	9	0.007(0.002–0.022)	
Root vegetables	25	0.008(0.003–0.015)	0.5
Raphanus sativus L./Chinese radish	11	0.008(0.005–0.012)	
Ipomaea batatas (L.) Lam/potato	14	0.008(0.003–0.015)	
Beans	59	0.007(0.001–0.051)	0.5
Vicia faba L./broad beans	18	0.006(0.001–0.015)	
Vigna sinensis (L.) Savi/cowpea	32	0.006(0.002–0.016)	
Glycine max (L.) Merr./edamame bean	9	0.013(0.004–0.051)	
Fruits	11	0.017(0.006–0.057)	0.5

[a] maximum allowable levels of contaminants in food (GB 2762-2012).
[b] set for inorganic As (GB 2762-2012).

2.2. Laboratory analyses

The details of the laboratory analyses of rice, vegetables and soil were the same as those described in our previous research (Cao et al., 2010). The ground fish (2.0 g fish fillet), shrimp (2.0 g shrimp meat) and crab samples (2.0 g crab meat and crab cream) were treated with 15 mL of HNO_3 (v:v, HNO_3:H_2O=2:1) in a Teflon container overnight respectively. The ground pork samples (1.5 g) were treated with 10 mL of HNO_3 in a Teflon container overnight. The ground egg samples (5.0 g) were treated with 15 mL of HNO_3 (v:v, HNO_3:H_2O=2:1) in a Teflon container overnight. These