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Comparison of Plasma Concentrations of Mercury, Cadmium, and Arsenic among Women in 2005 and 2012 in a Historically Contaminated Area in China

Lei Jin[1] · Jing-ru Yu[2] · Le Zhang[1] · Ai-guo Ren[1]

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Abstract

Mercury (Hg), cadmium (Cd), and arsenic (As) concentrations in women were measured and compared to evaluate the effects of environmental heavy-metal pollution control on internal exposure levels. In 2005 and 2012, 200 and 182 women, respectively, were enrolled in the study. Demographic and diet information were collected using a questionnaire. Fasting venous blood samples were collected, and plasma concentrations of Hg, Cd, and As were measured using inductive coupled plasma mass spectrometry. The median concentrations (P_{25}–P_{75}) of Hg, Cd, and As decreased from 0.56 (0.46–0.75) ng/mL, 0.14 (0.09–0.21) ng/mL, and 0.83 (0.66–1.09) ng/mL in 2005 to 0.39 (0.19–0.66) ng/mL, 0.09 (0.05–0.13) ng/mL, and 0.48 (0.29–0.72) ng/mL in 2012, respectively. The difference in plasma metal concentrations between measurements in 2005 and 2012 remained statistically significant after we adjusted for confounders. The adjusted ORs were 0.31 (0.16–0.60), 0.24 (0.12–0.48), and 0.25 (0.13–0.50) for Hg, Cd, and As concentrations, respectively, in 2012, relative to those in 2005. The levels of Hg, Cd, and As were 30% to 40% lower in 2012 than in 2005, indicative of lower human internal exposure to these contaminants due to the implementation of environmental pollution control. Engagement with agriculture and high-frequency water product consumption were associated with high Hg levels, and a high frequency of consumption of fresh fruit and eggs was negatively associated with lower levels of Cd in plasma.

Keywords Mercury · Cadmium · Arsenic · Plasma · Element · Woman

Introduction

In general, heavy metals are persistent and tend to accumulate in different environments. Because few metals are eliminated through chemical and biological means, they remain in the environment as a threat to human health [1]. Environmental pollution by heavy metals is caused by the burning of fossil fuels, municipal waste, sewage, pesticides, the smelting of metalliferous ore, fertilizers, and mining, which result in the contamination of aqueous waste streams, groundwater, and soil [2]. Environmental contamination by heavy metals has increased since 1900 [3] and is a worldwide problem. Exposure to heavy metals can damage the circulatory and urinary systems [4, 5], compromise neurological functioning [6, 7], and cause cancer; maternal exposure to toxic heavy metals may even have serious health consequences for the offspring [8, 9]. As industrialization has increased, water, air, and soil contamination, including contamination with mercury (Hg), cadmium (Cd), and arsenic (As), has become widespread in some areas of China [10–12]. In 2007, China issued its first *National Environment and Health Action Plan (2007–2015),* which called for the establishment of a nationwide surveillance network for the environment and health in which government agencies and other stakeholders could share information and take responsibility. According to that action plan, the Chinese government would, by 2015, conduct national surveys on the nature and extent of environmental pollution and its impact on health to form a comprehensive and efficient system to protect environmental health. For this purpose, the Chinese government has

✉ Lei Jin
jinlei@bjmu.edu.cn

1 Institute of Reproductive and Child Health, Peking University/Key Laboratory of Reproductive Health, National Health Commission of the People's Republic of China; Department of Epidemiology and Biostatistics, School of Public Health, Peking University, No. 38 Xueyuan Road, Haidian District, Beijing 100191, China

2 Department of Medical Epidemiology and Biostatistics, Karolinska Institute, Nobels väg 12A, 171 77 Stockholm, Sweden

invested as much as 66 billion US dollars, 1.49% of China's GDP in 2008 [13]. However, the assessment of the effects of pollution control on human internal exposure to contaminants has been limited.

Wuming County, in the Guangxi Zhuang Autonomous Region, has an abundance of copper (Cu), manganese (Mn), and tungsten (Wu) as well as gold mines and ores. Mineral mining has been ongoing for decades in the county, and the environment has been seriously polluted. In 1990, the local government launched a campaign to punish enterprises that illegally discharge pollutants. By November 2006, Wuming County was approved as a national ecological demonstration area, but no systematic study has been conducted since to assess the effects of changes in the environment on health after pollution control. The Bansu vein of manganese ore is in the township of Shuangqiao in Wuming. It has been mined since the 1960s, and the area of excavation totals over 1000 acres. Serious ecological destruction and heavy-metal pollution have occurred, with nearly 30 years of continuous exploitation and deterioration of original vegetation [14]. However, in the 1990s, as a result of restoration projects implemented by the federal government, this area became recognized as an example of ecological restoration in the Guangxi Autonomous Region [15, 16]. However, to date, no research on human internal exposure to contaminants has been reported for the area.

Most women aged 18 to 30 years are mothers or in the prepregnancy period. Their health status is closely associated with the health of their offspring because of pregnancy or lactation. In 2005 and 2012, we conducted two cross-sectional surveys among women aged 18 to 30 years old in the townships of Ganxu and Taiping, respectively, which neighbor Shuangqiao. Samples of blood plasma were collected for both surveys. We found that the median concentration of Pb in plasma in 2012 was almost double that in 2005 [17]. This study compared Hg, Cd, and As concentrations in plasma in 2005 and 2012 among rural women in this area.

Materials and Methods

Research Fields

We conducted two cross-sectional surveys among women aged 18 to 30 years old in the townships of Ganxu and Taiping in Wuming County in 2005 and 2012, respectively. Wuming is surrounded by mountains in the middle of a basin. Ganxu and Taiping are in the south of the county, and both are near Shuangqiao, where the Bansu manganese ore is located (Fig. 1).

Enrollment, Interviews, and Blood Collection

Subject enrollment, interviews, and blood collection were performed by doctors and nurses at a local maternal and child health hospital who were trained for the investigation. The study subjects were 18 to 30 years old, healthy, non-pregnant, non-lactating women who were living in Ganxu or Taiping. One or more villages near the township hospital were selected for inclusion in the study. Women with a history of occupational Hg, Cd, or As exposure (e.g., mine workers, potters, painters, oilers) according to self-report or report by the village doctor were excluded. A total of 200 and 182 women were enrolled in 2005 and 2012, respectively.

After consent was obtained, a structured questionnaire was administered by local healthcare workers using face-to-face interviews. The information gathered included age, occupation, education, marital status, family size, food intake, smoking habits, exposure to secondhand smoke, frequency of intake of certain foods, source of drinking water, and other lifestyle characteristics.

Fasting venous blood samples were collected from women in 4 mL heparin lithium tubes (Becton, Dickinson, Sparks, MD, USA) at the time of recruitment. Blood samples were centrifuged within 15 min of collection, and plasma was transferred to deionized propylene cryogenic tubes (Greiner Bio-One, Monroe, NC, USA). Then the plasma samples were frozen at −20 °C in the laboratory of the county maternal and child health station. Within 1 month of collection, the samples were shipped on dry ice to Peking University Health Science Center, where they were frozen at −80 °C until assay.

Laboratory Measurements

Plasma Hg, Cd, and As concentrations were determined in the bio-metallomics laboratory at the Peking University Medical and Health Analysis Center.

In all plasma samples collected in 2005 and 2012, concentrations of Hg, Cd, and As were measured with inductively coupled plasma mass spectrometry (ICP-MS; Agilent 7700x, Agilent Technologies, Santa Clara, CA, USA) in 2013. The plasma samples were prepared for ICP-MS as follows: 0.5 mL of the plasma was digested in a solution of 1.5 mL nitric acid (BV-grade III) and 0.5 mL H_2O_2 in a high-pressure microwave digestion system (Milestone, Ultra WAVE, Milan, Italy) with quartz vessels. After digestion, the samples were brought to a final volume of 7 mL with high-purity deionized water.

Certified standards from Chinese national reference materials (GSB 04–1729-2004 for Hg, GSB 04–1721-2004 for Cd, and GSB 04–1714-2004 for As) were used to calibrate and validate the standard curves. Indium and rhodium solutions were used for the online standardization of ICP-MS analysis. To check for possible contamination during the digestion and

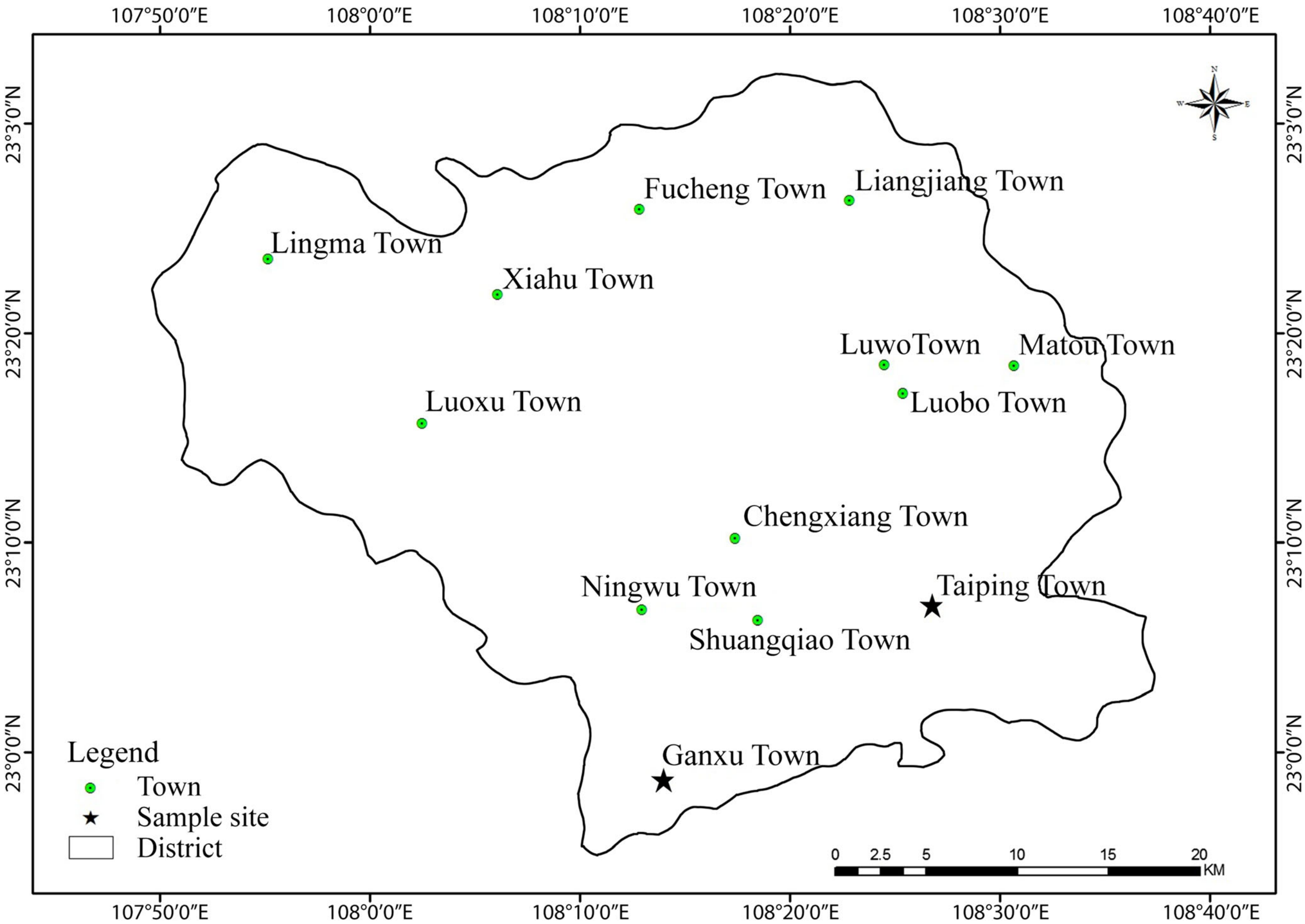

Fig. 1 Location of the two survey sites of Ganxu and Taiping, as well as Shunagqiao, where the Bansu manganese mine is located

manipulation of samples, we prepared and assayed a blank solution alongside each of the 20 samples. The recovery rates were 104% to 112% for As, 99% to 140% for Hg, and 91% to 150% for Cd. The same equipment was used to analyze the 2005 and 2012 samples. Samples collected in 2005 were frozen at −80 °C until they were analyzed in parallel with the samples from 2012. All of the regression lines for the calibration curves had correlation coefficients of more than 0.999. Samples of standard materials (ClinChek® Plasma Control for Trace Elements) with known reference concentrations of Hg, Cd, and As were prepared to check the stability of the process. Operators were blind to the year of plasma collection.

The limits of detection for Hg, Cd, and As were 0.08 ng/mL, 0.012 ng/mL, and 0.153 ng/mL, respectively. If the concentration of an element was lower than the limit of detection, it was recorded as zero.

Overexposure Criteria

Overexposure to Hg, Cd, and As was determined according to the following criteria: > 1.01 ng/mL Hg, > 0.04 ng/mL Cd, and > 7.58 ng/mL As [18].

Statistical Analyses

Differences in demographic characteristics between 2005 and 2012 were compared with the chi-square test (or Fisher's exact test, if the predicted number of subjects in any category was less than five). Medians and interquartile ranges were used to describe the average level and variability of the data for element concentrations. Concentrations of Hg, Cd, and As were compared between the two surveys, and nonparametric tests (Mann–Whitney U tests) were performed to compare the distributions. The subjects were divided into two levels according to the medians of the element concentrations, with the higher concentration recorded as 1 and the lower one recorded as 0. The confounders associated with the higher concentration of elements were explored with a chi-square test. The confounders included age, education level, occupation, and eating patterns. Stepwise logistic regression models were used to calculate the adjusted ORs and 95% CIs. Variables for which *P* was less than 0.05 in univariate analyses were used in multivariate logistic regression analyses, along with other variables including year of investigation and demographic characteristics (including age, education, occupation, and so forth).

Results

Characteristics of the Subjects

Table 1 gives a comparison of the demographic characteristics of the subjects enrolled in 2005 and 2012. The differences in mean age, marital status, and number of family members did not differ between 2012 and 2005 to a statistically significant extent ($P > 0.05$). The women investigated in 2012 had higher levels of education than those in 2005 ($P < 0.05$).

Plasma Concentration Levels of Hg, Cd, and As

As shown in Table 2, the median concentrations (P_{25}–P_{75}) of Hg, Cd, and As decreased from 0.56 (0.46–0.75) ng/mL, 0.14 (0.09–0.21) ng/mL, and 0.83 (0.66–1.09) ng/mL in 2005 to 0.39 (0.19–0.66) ng/mL, 0.09 (0.05–0.13) ng/mL, and 0.48 (0.29–0.72) ng/mL in 2012, respectively. Table 3 shows women whose concentrations of contaminants exceeded the upper reference limits in 2005 and 2012. The rate for Cd was not greatly different between 2005 and 2012. However, the rate for Hg was significantly lower in the 2012 sample than in the 2005 sample. No women in 2005 or 2012 had As concentrations over the upper reference limit.

Association between Investigation Year and Metal Concentrations

The ORs of the associations between Hg, Cd, and As concentrations and investigation years were 0.34 (0.22–0.52), 0.22 (0.14–0.34), and 0.15 (0.10–0.24) in univariate analyses (Table 4). After adjusting for potential confounders, the years of investigation remained the most important factor in the model. As shown in Table 4, the adjusted ORs were 0.31 (0.16–0.60), 0.24 (0.12–0.48), and 0.25 (0.13–0.50) for Hg, Cd, and As concentrations for 2012 compared to 2005. In addition, women who engaged in agriculture and who consumed more water products were more likely to have Hg concentrations exceeding the reference limit, and women who ate fewer eggs and less fresh fruit were more likely to have Cd concentrations exceeding the reference limit.

Discussion

The plasma concentrations of Hg, Cd, and As of women aged 18 to 30 years old in two townships in Wuming County, China, were significantly lower in 2012 than in 2005. The trend for Hg concentration is inconsistent with previously reported element concentrations in umbilical cord blood among

Table 1 Demographic characteristics of subjects in 2005 and 2012

Demographic characteristics	2005 ($n = 200$)	2012 ($n = 182$)	P
Location			
Ganxu	100 (50.0)	85 (46.7)	0.52
Taiping	100 (50.0)	98 (53.8)	
Age (years)			
18–24	46 (23.0)	58 (31.9)	0.057
25–26	75 (37.5)	50 (27.5)	
27–30	79 (39.5)	74 (40.7)	
Occupation			
Farmer	198 (99.5)	147 (81.2)	< 0.001
Others	1 (0.5)	34 (18.8)	
Education			
Less than primary school	77 (38.7)	32 (17.5)	< 0.001
Junior high school	111 (55.8)	124 (67.8)	
High school or more	11 (5.5)	27 (14.8)	
Marital status (proportion)			
Married	184 (92.0)	166 (91.2)	0.780
Unmarried	16 (8.0)	16 (8.8)	
Family scale (person, means ± standard deviation [SD])	4.1 ± 1.3	4.3 ± 1.2	0.083
Smoking (proportion)	0	0	–
Secondhand smoke (proportion)	5 (2.5)	12 (6.6)	0.052

Table 2 Median plasma concentrations of Hg, Cd, and As (ng/mL) among women aged 18 to 30 years old in Wuming County in 2005 and 2012

Elements		N	Median (P_{25}–P_{75})	Minimum	Maximum
Hg (ng/mL)	2005	200	0.56 (0.46–0.75)	0.21	39.47
	2012	181	0.39 (0.19–0.66)	nd	49.85
Absolute difference	2012–2005	–	−0.17**	−0.21	−10.38
Relative difference (%)			30		
Cd (ng/mL)	2005	200	0.14 (0.07–0.18)	nd	2.18
	2012	182	0.09 (0.05–0.13)	nd	2.73
Absolute difference	2012–2005	–	−0.05**	nd	−0.55
Relative difference (%)			36		
As (ng/mL)	2005	200	0.83 (0.66–1.09)	0.2	2.86
	2012	182	0.48 (0.29–0.72)	nd	3.10
Absolute difference	2012–2005	–	−0.35**	−0.2	−0.24
Relative difference (%)			42		

*The absolute difference between subjects in 2012 and in 2005, where values over zero indicate that concentrations of the element were higher in 2012, and values less than zero indicate that the concentrations were lower in 2012. Relative difference (%) = absolute difference/concentration in 2005 * 100%. Mann-Whitney U tests were used to compare the women in 2012 with the women in 2005. nd: not detected

**$p < 0.01$

fetuses in eastern China from 2006 to 2012; for example, Hg levels increased from 1.88 to 2.07 ng/mL from 2008 to 2011 [19, 20].

The trends in changes in As concentrations in our study are consistent with changes in As concentrations in umbilical cord blood and fetal hair among newborns in Shanghai from 2006 to 2009 [20, 21], which decreased from 2.84 ng/mL to 0.86 ng/mL. However, our trends for Cd are inconsistent with those for Cd from fasting venous blood in healthy young men and pregnant women in eastern China from 2006 to 2012 [21–23], which were 0.8 and 0.9 ng/mL among young men and women in 2006 and 2012, respectively [21, 22]. Further, the fasting venous blood concentrations of Hg were 1.88 and 2.07 ng/mL among young men and women in 2006 and 2012, respectively. Our results may differ from previous studies due to variation in Hg, Cd, and As pollution and the various sources of pollution in different regions in China [24–26].

Our study populations may have had lower concentrations of Hg, Cd, and As in plasma in 2012 versus 2005 due to the improvements in the ecological environment in the area of the Bansu manganese ore mine. The women in this study lived in Ganxu and Taiping, near the manganese ore mine (Fig. 1). The

Table 3 Rates of concentrations of Hg, Cd, and As over the upper reference limits in the 2005 and 2012 populations

Elements	Criteria (ng/mL) (ULR)	Year	Total	OULR	POULR (%)	χ^2	*p*-values
Hg	< 1.01 ng/mL) [18]	2005	200	24	12.0	0.257	0.612
		2012	182	25	13.7		
		Total	382	49	12.8		
Cd	< 0.04 ng/mL) [18]	2005	200	184	92.0	–	Fisher's exact test $p = 0.005$
		2012	182	150	82.4		
		Total	382	334	87.4		
As	< 7.58 ng/mL) [18]	2005	200	0	0.0	–	–
		2012	182	0	0.0		
		Total	382	0	0.0		

ULR: upper limit of reference; OULR: over the upper limit of reference; POULR: proportion of women with concentrations over the upper limit of reference

Table 4 Factors associated with high levels (higher than the medians of the total sample) of Hg, Cd, and As in plasma in multivariate logistic regression models

Elements	Variables	Values	N	Over the median n (%)	Univariate model OR (95% CI)	Multivariate model OR (95% CI)
Hg						
	Year					
		2005: 0	200	123 (61.5)	1	1
		2012: 1	182	64 (35.4)	0.34 (0.23–0.52)	0.31 (0.16–0.60)
	Occupation					
		Farmer: 0	344	175 (51.0)	1	1
		Others: 1	35	11 (31.4)	0.44 (0.21–0.93)	0.26 (0.08–0.85)
	Fresh water production					
		≥ 1 time/month: 0	85	50 (58.8)	1	1
		< 1 time/month: 1	297	137 (46.2)	0.63 (0.27–1.49)	0.14 (0.04–0.47)
	Location					
		Ganxu: 0	182	93(51.1)	1	1
		Taiping: 1	200	94(47.0)	0.96 (0.78–1.16)	1.01 (0.59–1.72)
Cd						
	Year					
		2005: 0	200	134 (67.0)	1	1
		2012: 1	182	56 (30.8)	0.22 (0.14–0.34)	0.23 (0.11–0.46)
	Eggs					
		> 3 times/week: 0	163	52 (31.9)	1	1
		< 3 time/week: 1	216	136 (63.0)	3.63 (2.36–5.58)	2.17 (1.23–3.82)
	Fresh fruit					
		> 1 times/day: 0	143	50 (35.0)	1	1
		< 1 time/day: 1	238	140 (58.8)	2.66 (1.73–4.08)	1.96 (1.14–3.36)
	Location					
		Ganxu: 0	182	75 (24.7)	1	1
		Taiping: 1	200	115 (57.5)	1.43 (1.17–1.75)	2.03 (1.15–3.58)
As						
	Year					
		2005: 0	200	141 (70.5)	1	1
		2012: 1	182	48 (26.4)	0.15 (0.10–0.24)	0.25 (0.13–0.50)
	Township					
		Ganxu: 0	182	81 (44.5)	1	1
		Taiping: 1	200	109 (54.5)	1.27 (1.04–1.55)	2.01 (1.13–3.58)

The response variable codes for the logistic models were 1 for higher than median concentration and 0 for lower than median concentration. The Cox & Snell R^2 values for the univariate models of association between year and higher level of Hg, Cd and As were 0.072, 0.137, and 0.201, respectively. All of the p values for the models were less than 0.001. The adjusted Cox & Snell R^2 values for the multivariate models of Hg, Cd, and As were 0.117, 0.225, and 0.233, respectively. All of the p values for the models were less than 0.001

part of the ore vein located between the villages of Lelou and Tanbi is distributed over about 5 km^2 and was originally covered in forest, grassland, fruit trees, and dryland. Mining of the ore began in 1964, and it was among the most important drivers of the economy of Wuming for four decades. During that time, an area over 1000 acres in size was excavated, resulting in the deterioration of the original vegetation, serious ecological destruction, and pollution by heavy metals [27]. The government of the Guangxi Zhuang Autonomous Region published management measures in 1992 [28] requiring mines in the region to implement environmental protection measures regarding their emissions of waste water, waste gas, and solid waste. It required miners to conform to environmental requirements and work to reclaim land destroyed by mining. Later, the government issued rules and regulations regarding types of ores and required mining organizations to improve polluted rivers. Ultimately, due to the success of these efforts, the mining area became heralded as an example of ecological restoration in Guangxi [15, 16].

The consumption of contaminated water and seafood (including fish, shrimp, and shellfish) is the most important routes of exposure to methylmercury [29–31]. In our study,

Table 5 Median concentrations of Hg, Cd, and As (ng/mL) in our study compared with the results of other published studies

References	Research fields	Subjects	N	Elements	Methods	Median (P_{25}–P_{75})[a] (ng/mL)
[50]	Italy, Rome	Healthy urban population	110	Hg Cd	ICP-MS	1.28 (0.80–1.70) 0.09 (0.06–0.12)
[51]	France	Healthy population	100	Cd	ICP-MS	0.03 (0.01–0.05)[b]
				As		6.2 (4.4–14.2)[b]
[52]	Sweden, Uppsala	70-year-olds	1016	Hg	ICP-SFMS	4.20 (2.80–6.30)
[18]	France	Healthy volunteers, 2012	106	Hg	ICP-MS	0.36 (0.09–1.01)[b]
				Cd		< 0.03 (< 0.03–0.04)[b]
				As		2.19 (1.55–7.58)[b]
[53]	Hong Kong	General population	151	Hg	DHA	0.63
[54])	Germany	General population	29	Hg	CVABS	0.23
[55]	China, 2002	Children aged 3–12 years		Cd	HR-ICP-MS	64.53
				As		1.17
[56]	Xiamen, China, 2010	Healthy pregnant women aged 25 ± 4 years	40	Cd	ICP-MS	0.29 (0.15–0.51)
			104	As		5.72 (3.39–9.33
This study	China, 2005	Women aged 18 to 30 years	200	Hg	ICP-MS	0.56 (0.46–0.75)
				Cd		0.14 (0.09–0.21)
				As		0.83 (0.66–1.09)
This study	China, 2012	Women aged 18 to 30 years	182	Hg		0.39 (0.19–0.66)
				Cd		0.09 (0.05–0.13)
				As		0.48 (0.29–0.72)

[a] 5th–95th percentile; [b] 25th–75th percentile; CVABS: cold vapor atomic absorption spectrometry; DHA: direct Hg analyzer; HR-ICP-MS: high-resolution inductively coupled plasma mass spectrometry; ICP-MS: inductively coupled plasma mass spectrometry; ICP-SFMS: inductively coupled plasma sector field mass spectrometry

we found that a high frequency of freshwater products consumption was associated with higher levels of Hg. Polluted rice is the main path for Hg in China and other areas in Asia [32, 33]. Rice is the staple for the local population, and improvement of environmental pollution could reduce levels of Hg in rice and reduce exposure to Hg among the population. However, we did not collect information on rice consumption in this study, making it impossible to determine any association between rice consumption and Hg levels. We found that women engaged in agriculture had higher levels of Hg than other women. In cultivated soils in China, Hg concentrations are significantly higher than the reference background level [34], and women who work in fields come into closer contact with soil and for longer periods, which may explain their higher levels of Hg.

Among the general population, a major mean of exposure to environmental Cd is food. Cereals, vegetables, and seafood contribute 80% of total Cd exposure in China [35]. However, we did not find an association between vegetables or seafood consumption and Cd levels in this study. This may result from the low frequency of seafood consumption among the subjects in this study. Only 0.5% (1/200) and 12.2% (22/182) of respondents in 2005 and 2012, respectively, consumed marine products once or more per month. No information on the consumption of cereals was collected in this study. We did not find a significant association between Cd levels and consumption of vegetables, implying a need to research this further. Smoking also constitutes an important pathway for environmental Cd exposure in the general population [36, 37]. However, we did not find a significant association between plasma Cd levels and smoking or exposure to secondhand smoke. This is likely because almost no women in this study smoked, and the proportion of exposure to secondhand smoke was less than 7%.

In this study, women who ate more eggs or fresh fruit had a lower rate of Cd concentrations exceeding the reference limit. The fruit-producing area near Wuming in Guangxi is free of heavy-metal pollution [38, 39], and fruit and eggs in the markets are not polluted by Cd [40–42]. Someone who consumes more fresh fruits or eggs may have good nutritional balance and have a stronger capability to excrete any heavy metals that accumulate [43], as has been observed in rats [44]. Grosicki showed that vitamin C supplements decrease Cd burden and content in the liver, kidneys, testicles, and muscles in the rat model [44].

Exposure to As can occur through contaminated drinking water, food, cigarettes, one's occupational environment, and the air [45, 46]. Drinking water is the largest source of As poisoning worldwide. Exposure from ingested foods usually comes from food crops grown in As-contaminated soil and/or irrigated with As-contaminated water [47–49]. Levels of As decrease as environmental pollution improves, which may explain why plasma levels of As were lower in the 2012 sample than in the 2005 sample.

The concentrations of Hg, Cd, and As documented in our study are greater than those in some developed countries but lower than those in some other regions of China (Table 5). For example, the median concentration of Hg in the plasma of females selected in 2005 was higher than those reported in a healthy French population in 2013 [18], among the general population of Germany in 1998 [54], and in a healthy urban population in Italy in 2005 [50]. However, it was lower than those reported in the elderly in Sweden [52] and residents in Hong Kong [53]. Our value for 2012 was still higher than that of the general population in Germany in 1998 [54] and near the level of the healthy population in 2013 in France [18]. Similarly, our Cd values for 2005 were higher than those of the healthy French population in 2013 [18] and the healthy urban population in Italy in 2005 [50] but lower than the values for pregnant women in Xiamen [56] and children aged 3–12 years old in a national nutrition and health survey conducted in 2002 [55]. The values for 2012 were still higher than that of the healthy population of France [18, 51] and equal to the level of the healthy population in Italy [50]. Our concentrations of As for both years were lower than those reported in other studies in China [55, 56] and in other countries [18, 51].

In summary, we compared concentrations of Hg, Cd, and As in the plasma of women aged 18 to 30 years old in rural areas of China in 2005 and 2012 after adjusting for demographic characteristics, consumption of certain food items, and frequency of water consumption. To the best of our knowledge, this is the first time these factors have been investigated in Wuming County. The results could help local governments evaluate the effects of pollution control and make appropriate environmental protection policies. However, this study has some limitations. Concentrations of Hg, Cd, and As in food, water, and the soil were not measured, so we could not analyze levels of external exposure or their relationships to internal exposure in the participating women. Another limitation is that our study only included women aged 18 to 30 years old, so we do not know whether these results generalize to males or females of other ages.

Conclusions

The levels of Hg, Cd, and As in plasma tested in 2005 were lower than the levels in 2012 in women aged 18 to 30 years old, indicating that internal-exposure levels of Hg, Cd, and As were lower in 2012 than in 2005. Engagement with agriculture and a high frequency of water product consumption were associated with higher Hg levels, and high consumption of fresh fruit and eggs was correlated with lower Cd levels.

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Compliance With Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethics Approval The research protocol was approved by the institutional review board of Peking University (code: IRB00001052–14019), and informed consent was obtained from the subjects before the investigation.

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