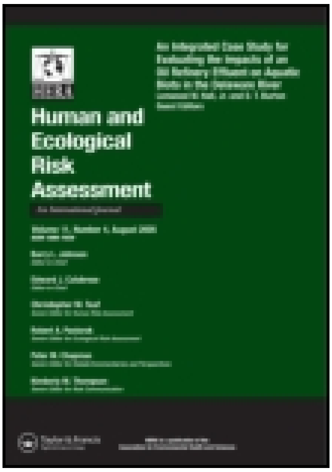

Human and Ecological Risk Assessment: An International Journal
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/bher20

Accumulation of Lead, Zinc, and Copper in Scalp Hair of Residents in a Long-Term Irrigation Area Downstream of the Second Songhua River, Northeast China

Hui Zhu [a] , Lilu Zhu [a b] , Baixing Yan [a] & Jiunian Guan [a c]

[a] Key Laboratory of Wetland Ecology and Environment, Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences , Changchun , Jilin Province , P.R. China

[b] Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences , Changchun , Jilin Province , P.R. China

[c] Graduate University of the Chinese Academy of Sciences , Beijing , China

Accepted author version posted online: 31 Oct 2012.Published online: 11 Oct 2013.

To cite this article: Hui Zhu , Lilu Zhu , Baixing Yan & Jiunian Guan (2014) Accumulation of Lead, Zinc, and Copper in Scalp Hair of Residents in a Long-Term Irrigation Area Downstream of the Second Songhua River, Northeast China, Human and Ecological Risk Assessment: An International Journal, 20:1, 137-149, DOI: 10.1080/10807039.2012.740655

To link to this article: http://dx.doi.org/10.1080/10807039.2012.740655

Human and Ecological Risk Assessment, 20: 137–149, 2014

ISSN: 1080-7039 print / 1549-7860 online
DOI: 10.1080/10807039.2012.740655

Accumulation of Lead, Zinc, and Copper in Scalp Hair of Residents in a Long-Term Irrigation Area Downstream of the Second Songhua River, Northeast China

Hui Zhu,[1] Lilu Zhu,[1,2] Baixing Yan,[1] and Jiunian Guan[1,3]
[1]Key Laboratory of Wetland Ecology and Environment, Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, Changchun, Jilin Province, P.R. China; [2]Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, Changchun, Jilin Province, P.R. China; [3]Graduate University of the Chinese Academy of Sciences, Beijing, China

ABSTRACT

In the present study, lead, zinc, and copper concentrations in scalp hair of 120 residents in a long-term irrigation area in downstream of the Second Songhua River were determined. The correlation between metals in hair and the subject descriptors (*i.e.*, age, gender, height, weight, smoking, and drinking habits) was determined, and the metals' contents in the commonly consumed foods and the local environment were also analyzed. The mean concentrations of Pb, Zn, and Cu in residents' scalp hair were 85.9 ± 51.1, 174.0 ± 31.1, and 6.7 ± 4.4 μg/g, respectively. Drinking habits influenced Pb contents significantly; the highest Pb concentrations were found in hair of residents who drink frequently, followed by those who drink occasionally and those who never drink. However, for Zn and Cu, no significant influence was found. There was no significant correlation between metal contents and age, gender, or smoking habits ($p > .05$). However, a significant positive correlation ($p < .01$) was observed between Zn contents in hair and height. In general, the concentrations of metals in most of the food and the local environments meet China's or other standards. However, it is still necessary to pay attention to Pb pollution in the study area for public health.

Key Words: heavy metals, scalp hair, diet, soil, water, the second Songhua River.

Received 22 July 2012; revised manuscript accepted 28 September 2012.
Address correspondence to Lilu Zhu, Key Laboratory of Wetland Ecology and Environment, Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, 4888 Shengbei Street, Changchun, Jilin Province 130102, P.R. China. E-mail: zhulilusina@163.com; zhuhui@neigae.ac.cn

INTRODUCTION

Metals are widespread and non-degradable in the environment, some of which could be toxic even at low intake levels, while others are essential to serve specific biological functions, but they can also be toxic when present in excess (Rivai 2001). For example, excessive Pb exposure may result in learning disability and hypoevolutism (Tuthill 1996; Selevan *et al.* 2003; Torrente *et al.* 2005); chronic occupational exposure to Cu alone or in combinations with other heavy metals (Cu, Pb, and Fe) is associated with Parkinson's disease (Gorell *et al.* 1999). Among the metals, Pb, Zn, and Cu, which affect human health significantly, are frequently studied due to their extensive use in industry and agriculture and their high concentrations in the environment. Heavy metals released into aquatic or soil environments can be translocated into the food chain and ultimately affect human health by biomagnification (Yeganeh *et al.* 2012; Qu *et al.* 2012). Therefore, efforts to monitor and control heavy metals' contaminations are crucial for individuals at risk.

Various biological materials such as hair, human milk, blood, urine, and nails have been used to determine trace element concentrations in epidemiological surveys (Mehra and Juneja 2005; Liu *et al.* 2008; Gerhardsson and Lundh 2010). Compared with other biological materials, hair is easy to collect, transport, and store (Zaida *et al.* 2007). Furthermore, elements in human scalp hair reflect accumulation over a longer period and trace element concentrations in hair are considerably higher than those in blood and urine (Hauser *et al.* 1999; Afridi *et al.* 2012; Baig *et al.* 2011). As a result, hair has been widely used in recent studies (Hauser *et al.* 1999; Gerhardsson and Lundh 2010; Olmedo *et al.* 2010; Wang *et al.* 2009). Previous researches have reported the influence of food, environment, health, age, gender, race, and hair color on the concentration of various elements in hair (Sturaro *et al.* 1994; Mehra and Juneja 2004; Razagui and Ghribi 2005; Unkiewicz-Winiarczyk *et al.* 2009). However, limited studies have focused on the influence of alcohol drinking to human heavy metal burden. Afridi *et al.* (2011) revealed high exposure of trace metals in hypertensive patients as a result of alcohol consumption. However, for normal groups, the knowledge on the influence of alcohol consumption of trace metals' accumulation in scalp hair is not available.

The Second Songhua River, which is one of the most important rivers in Northeast China, had suffered serious heavy metals/pollution due to the direct discharging of industrial effluent during the 1960s to 1970s (Lin *et al.* 2008). Although the outflows were cut off in 1982, and the pollution has been effectively controlled for more than three decades by environmental governance and natural purification (Zhu *et al.* 2012), there is still potential possibility that the residents living in the basin may be exposed to heavy metals due to the consumption of food correlated with the river (rice in paddy fields with long-term river water irrigation, fish from the river, *etc.*), and exposure in the local environment, especially for the residents living downstream of the Second Songhua River. However, the relevant information was limited at present.

Therefore, the current study was performed in the Qianguo Irrigation Area, a long-term irrigation area downstream of the Second Songhua River, Northeast China, in order to investigate the concentrations of Pb, Zn, and Cu in scalp hair, diet, and the local environment and discuss the influences of human descriptors (age, gender, weight, height, smoking, and drinking habits) and environmental descriptors (soil, surface water, and food) on concentrations of metals in human scalp hair.

METHODS AND MATERIALS

Study Area

The Qianguo Irrigation Area with more than 50 years irrigating history is located in the downstream of the Second Songhua River, Northeast China (Figure 1). It lies in 124°05′10″∼124°06′50″ E and 44°18′30″∼45°06′40″ N. The climatology of the region is that of a mid-temperate zone. The annual mean air temperature is 4.5°C and the frozen period lasts from October to the next May, with the lowest temperature recorded as –36.1°C. The annual mean precipitation is 451.8 mm, which is only one-third of the annual mean evaporation capacity (1510 mm). Large-scale intensive paddy fields were developed in this area more than 50 years ago. During these decades, the paddy fields in this area received irrigation water for rice production year-by-year, and the main irrigation water is pumped from the Second Songhua River and delivered to the paddy fields through ditches. A railway and two national highways cross the area. In addition, a lot of pumping units and roads were distributed throughout the area. However, the development of this area is based on agriculture, and the point pollution sources were not detected, which indicates the soil and aquatic systems of the area are not likely to be exposed to significant industrial and domestic pollution. Also, the backwardness of transportation and industry lead to very little metal disposition on human hair via air pollution.

Sample Collection

Hair samples were randomly collected from 20 females and 100 males, residents of the study area in winter 2009 (age ranged 1–76 yr, all selected subjects were healthy, had no direct exposure to metals, and had not used any mineral supplements).

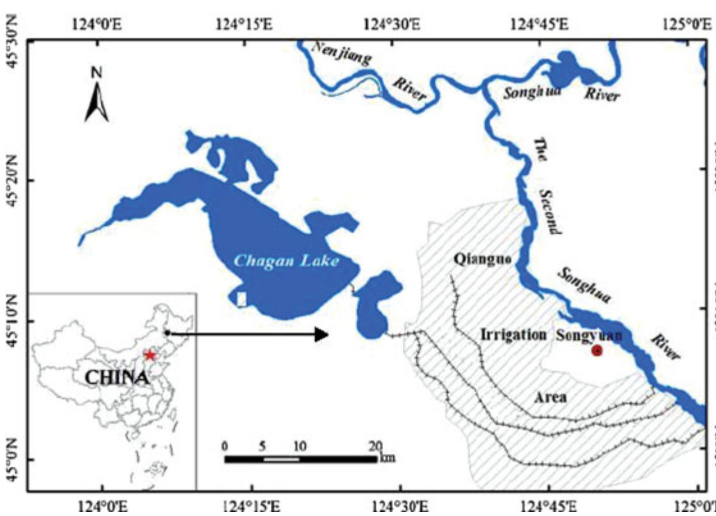

Figure 1. Location of the Qianguo Irrigation Area. (Color figure available online.)

None of the females were pregnant. The individuals or their parents (for the infants and children) were informed about the aim of the investigation and delivered their consent to participant in the study. Hair samples were collected from the nape of each individual's neck by a pair of stainless steel scissors soaked in alcohol prior to each collection. Approximately 3 g of hair with an average length of 5 cm was collected and individually placed in a coded polyethylene zip-bag. A questionnaire covering age, gender, height, weight, smoking and drinking habits, and diet of the individuals was completed simultaneously. In the questionnaire, drinking habit was described as three levels: frequently drink, occasionally drink, and never drink. Here, frequently drink was defined as: a person who drinks three or more times a week, or the total amount of alcohol consumption is greater than 500 mL/week, and occasionally drink was defined as: a person who drinks one or two times a week, or the total amount of alcohol consumption is less than 500 mL/week. The diet investigation included the diet habit (kinds of the stable food and the main protein sources, *etc.*) as well as the diet intake amount.

A total of 63 agricultural soil and 23 rice plant samples were collected from paddy fields in the Qianguo Irrigation Area in fall 2009. At each sample site, surface soil samples (0∼20 cm depth) and rice panicle were collected by a random sampling method. Approximately 1 kg of soil and 0.5 kg of rice panicles were collected and individually bagged in coded polyethylene zip-bags.

Fish is one of the most common daily foods in the study area, and fish consumption is widely reported as a most common pathway for human exposure to heavy metals due to the biomagnification effect (Zhu *et al*. 2012). Therefore, fish was chosen as another studied diet in addition to rice in the present study. Fish samples in the area were randomly collected in winter 2009 from Chagan Lake and the Second Songhua River by trawling. We selected three commercial fish species, bighead carp (*Aristichthys nobilis*), crucian carp (*Carassius carassius*), and silver carp (*Hypophthalmichthys molitrix*) for investigation because these fish species are more than 80% of the fish consumed in this area. When the fish were collected by trawl net, these species were selected for investigation, and the other species that are not commonly consumed were released into the river and/or lake. In the field, all fish were sampled by gloved personnel. After rinsing and bio-measuring, fish was individually wrapped and bagged in polyethylene zip-bags, chilled on wet ice, and brought to the laboratory.

Water samples were collected at the fishing points of the river and lake by polyethylene bottles (500 mL) previously washed using nitric acid solution and deionized water, then preserved by treating with nitric acid to reduce the pH < 2 in the field and kept at 4°C until further analysis.

Samples Pre-Treatment

The hair samples were washed in the laboratory with detergent, rinsed two times with acetone, then dried by natural air and cut into small pieces (shorter than 2 mm) with scissors (Liu *et al.* 2008). The soil samples were air-dried at room temperature, pulverized, and sieved through a 0.15 mm stainless-steel mesh. The rice panicles were thoroughly washed first with tap water, and later with 0.2 mol/L HCl and deionized water, air dried, chopped, and further dried for 24 h at 80°C (Gupta *et al.*

2008), then we separated rice flesh from hull. All the soil and plant samples were stored in polyethylene zip-bags until analysis.

The fish were filleted and approximately 4∼5 g of the epaxial muscle on the dorsal surface (representing the portion of fish normally consumed by humans) were dissected, washed with deionized water, dried on filter paper, weighed, and kept at −16°C until the performance of analysis. However, for small fish less than 50 mm in length, the entire edible part of each individual was included to prepare for the samples. Water samples were filtered and stored in polyethylene bottles at −16°C until further analysis.

Digestion Procedure

Weighed 150 mg of each hair, rice flesh powder (500 mg), and 500 mg of each fish muscle samples were placed in an Erlenmeyer flask and digested with a mixture of HNO_3-$HClO_4$ (5:1, *V/V*) (Barman and Lal 1994). Five hundred mg of each soil sample was placed in a PTFE container and digested with a mixture of HF-HNO_3-$HClO_4$ (1:5:1, *V/V/V*). All the mixtures were heated in a programmable heating block over a period of 12 h until a clear digestion solution was obtained. On completion of the digestion and after adequate cooling, solutions were filtered and diluted to a constant volume of 50 mL with deionized water.

Determination Procedure and Quality Control

The total concentrations of Pb, Zn, and Cu were determined by inductively coupled plasma-optical emission spectrometer (ICP-OES, Shimadzu Corporation, ICPS-7500). All samples were analyzed in triplicate.

Blank samples were prepared in the laboratory in a manner similar to the real samples. An independent calibration verification standard (National Certified Reference Materials of China) for each metal was analyzed at the beginning and end of each instrumental run to confirm the calibration status of the ICPS-7500 analyzer system. The percent errors were within 10% for 15 measurements of reference solutions used to verify instrument calibration during analysis of each metal. All analyses ($n = 10$) of certified reference material for soil (GBW-08513) and plant (GBW-08303) samples, obtained from the China National Center for Standard Reference Materials, were within the certified ranges. Method precision for total Pb, Zn, and Cu, determined as percent relative standard deviation (%RSD) from triplicate digestion, amalgamation, and analysis results were within 10%.

To minimize contamination, all the glass materials used in the experiments were previously immersed in 10% (*w/V*) nitric acid solution for 24 h and rinsed with deionized water over three times. All acids and chemicals were of guarantee reagent grade. Deionized water was used throughout the study.

Statistical Analysis

Pearson and Spearman correlation analysis was used to determine p values between metals' concentrations and subjects' descriptors such as weight and height. The partial correlation analysis was used under the condition that the variables were influenced by another subjects' descriptors. Statistical comparison among means of two groups was performed by Independent Sample T-Test while the statistical comparison of more than two groups was performed by one-way ANOVA. If ANOVA was significant, the Student-Newman-Keuls test was employed for the comparison. Differences were considered significant at $p \leq .05$. Statistical analysis was performed by SPSS software version 13.0 (SPSS Inc., Chicago, IL, USA).

RESULTS AND DISCUSSION

Heavy Metals in Human Scalp Hair

The concentrations of heavy metals in human scalp hair, presented by age, are listed in Table 1. The average concentrations of Pb, Zn, and Cu are 85.9 ± 51.1, 174.0 ± 31.1, and 6.7 ± 4.4 μg/g, respectively. The average concentration of Pb is comparable with that in the city of Mersin, Turkey (52.4 ± 31.2 μg/g) (Doğan-Sağlamtimur and Kumbur 2010), but higher than that in Harbin, China (21.9 ± 14.3 μg/g), Medan, Indonesia (40.4 ± 27.1 μg/g), and Tokushima, Japan (13.2 ± 14.8 μg/g) (Feng *et al.* 1997). The concentrations of Zn and Cu are comparable with those from the four cities cited (Feng *et al.* 1997; Doğan-Sağlamtimur and Kumbur 2010). However, so far, no relative standard has been established for Pb, Zn, and Cu contents in human scalp hair, which makes it difficult to assess its metal-related health risks.

According to the results of AVONA, there was no significant difference among the concentrations of trace elements in different age groups ($p > .05$). However, the relatively high average concentrations were observed in the group with age of more than 50 years old. A similar trend was revealed in the study carried out in the Veneto region of Italy, suggesting Zn concentration in human scalp hair increased with age (Sturaro *et al.* 1994). Nevertheless, some studies showed different results. For instance, Meng (1998) found the highest concentration of Zn in newborns' hair, followed by an increase from the baby group (<1 yr) to the puberty group (15∼19 yr), and a decrease with age from the puberty group to the elderly group (61∼70 yr), while the highest Pb concentration was observed in elderly group. This suggested that the age-related trace metals in hair may depend on different geographic regions.

Table 1. Concentrations of Pb, Zn, and Cu in human scalp hair (mean ± SD, μg/g).

Age	N	Pb	Zn	Cu
1∼20	22	84.1 ± 45.6	163.8 ± 38.3	6.0 ± 4.2
20∼30	44	84.5 ± 57.9	173.8 ± 30.4	6.3 ± 4.2
30∼40	31	83.12 ± 44.7	176.8 ± 26.4	6.0 ± 4.0
40∼50	13	81.4 ± 49.3	179.5 ± 32.7	8.9 ± 5.5
>50	10	110.5 ± 55.2	181.8 ± 27.9	8.7 ± 3.9
Total group	120	85.9 ± 51.1	174.0 ± 31.1	6.7 ± 4.4

N: number of subjects.

Correlations Between Metals' Contents and the Subjects' Descriptors

The subjects' descriptors are gender, smoking and drinking habits, height, and weight. It is shown in Table 2 that the Pb concentrations were significantly different among the residents with different alcohol drinking habit ($p < .05$). The higher Pb concentrations were observed in hair of residents who drink frequently, followed by those who drink occasionally and those who never drink. However, it was different for Cu and Zn, and no significant difference was found between the contents of Zn or Cu in scalp hair of residents with different drinking habits ($p > .05$). The smokers tend to accumulate more toxic elements (Pb) and less nutrient elements (Zn and Cu) than non-smokers, but the differences were not significant ($p > .05$). In addition, no significant differences were found in contents of Pb, Zn, and Cu in scalp hair of residents with different age, and gender ($p > .05$). There was a significant correlation ($p < .01$) between Zn concentration in human scalp hair and height while no correlation was found between other metals and height or weight (Figure 2).

Researches on the correlation between trace elements concentration and gender, race, hair color, and smoking habits have been reported. However, the results were not always the same, indicating the complexity of this issue (Sturaro *et al.* 1994; Mehra and Juneja 2004; Razagui and Ghribi 2005; Unkiewicz-Winiarczyk *et al.* 2009). For the influence of alcohol drinking habit on trace metal accumulation in human scalp hair, very few published articles are available. In the present study, it revealed a significant drinking habits-related difference of Pb concentrations. This should be considered especially in the health assessment of people who drink frequently and are exposed to Pb pollution.

Heavy Metals in Rice and Fish

The concentrations of researched metals in rice flesh, and fish from the Second Songhua River and Chagan Lake as well as the comparison with standard values are shown in Table 3. Considering all 23 rice flesh samples, the average concentrations of Pb, Zn, and Cu fit within the national standards established for Pb, Zn, and Cu

Table 2. Variation of Pb, Zn, and Cu concentrations in human scalp hair with subjects' descriptors.

Descriptor	N	Pb	p^*	Zn	p^*	Cu	p^*
Gender							
Male	100	88.6 ± 52.4	Ns	172.1 ± 28.1	Ns	6.4 ± 4.3	Ns
Female	20	72.6 ± 42.8		183.5 ± 42.8		7.8 ± 4.6	
Smoking habit							
Smoker	44	93.2 ± 49.3	Ns	173.5 ± 29.6	Ns	6.3 ± 4.3	Ns
Non-smoker	76	81.7 ± 52.0		174.3 ± 32.1		6.9 ± 4.4	
Drinking habit							
Frequently	19	112.8 ± 48.3	S	175.2 ± 26.8	Ns	6.7 ± 5.0	Ns
Occasionally	64	84.9 ± 51.8		175.8 ± 27.6		6.3 ± 4.5	
Never	37	74.0 ± 47.3		174.0 ± 31.1		7.2 ± 3.9	

N: number of subjects; *S: significant at $p < .05$, Ns: not significant at $p < .05$.

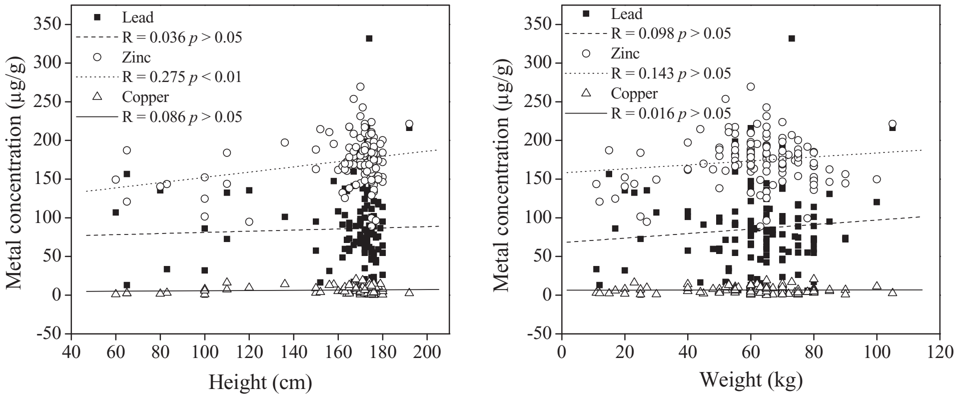

Figure 2. Correlations between Pb, Zn, and Cu concentrations in human scalp hair and height and weight.

in China (MOH of China 1991, 1994; MOH and SAC of China 2005). In addition, the concentration of Pb in rice also fits within international standards (EU 2008; CAC 2010). The average concentration of Pb in fish from Chagan Lake was within the national standards of China (AQSIQ of China 2001; MOH and SAC of China 2005) and the international standards (EU 2008; CAC 2010). However, for the fish

Table 3. Concentrations of Pb, Zn, and Cu in food of subjects (mean ± SD) and comparison with the standard values.

Values found in this study			Standard values
Rice flesh in study area (μg/g, dry weight) N = 23	Pb	0.19 ± 0.07	0.2 μg/g of Pb (MOH & SAC of China 2005)
	Zn	13.79 ± 1.88	0.2 μg/g of Pb (EU 2008)
	Cu	2.24 ± 0.91	0.2 μg/g of Pb (CAC 2010)
			50 μg/g of Zn (MOH of China 1991)
			10 μg/g of Cu (MOH of China 1994)
Fish from Chagan Lake (μg/g, wet weight) N = 44	Pb	0.17 ± 0.22	0.5 μg/g of Pb (MOH & SAC of China 2005)
	Zn	12.55 ± 13.89	0.5 μg/g of Pb (AQSIQ of China 2001)
	Cu	0.49 ± 0.25	0.3 μg/g of Pb (EU 2008)
Fish from second Songhua River (μg/g, wet weight) N = 14	Pb	2.30 ± 1.14	0.3 μg/g of Pb (CAC 2010)
	Zn	18.87 ± 11.75	50 μg/g of Zn (MOH of China 1991)
	Cu	1.52 ± 0.65	50 μg/g of Cu (MOH of China 1994)
			50 μg/g of Cu (AQSIQ of China 2001)

N: number of samples.

from the Second Songhua River, the Pb concentrations were significantly higher than those from Chagan Lake ($p < .05$) and exceeded standards ($p < .05$) (AQSIQ of China 2001; MOH and SAC of China 2005; EU 2008; CAC 2010). No relative international standards were established for Zn and Cu in fish. However, the Zn and Cu concentrations in the fish samples were all within the relative Chinese standard (MOH of China 1991, 1994; AQSIQ of China 2001).

In 2004, the Joint FAO/WHO Expert Committee on Food Additives (JECFA) established an allowable intake standard: Provisional Permissible Tolerable Weekly Intake (PTWI) recommending the intake amount of 25, 7000, and 3500 μg/week/kg bodyweight for Pb, Zn, and Cu, respectively. It was reported that the average bodyweight of Chinese adults is 55.9 kg (Wang *et al.* 2005). The average daily fish consumption in the region is less than 50 g per person (Zhang *et al.* 2008), which is equivalent to 350 g per person per week. The average daily rice consumption is approximately 400 g per day, which is also equivalent to 2800 g per person per week. Therefore, the estimated weekly intake values for trace metals were estimated by assuming that a 55.9 kg person consumes 350 g fish from the Second Songhua River (representing the maximum risks posed on human health) and 2800 g rice per week. As a result, the calculated values for Pb, Zn, and Cu were 14.4, 118.1, and 9.5 μg/week/kg bodyweight, respectively, based on fish consumption and 9.5, 690.7, and 112.2 μg/week/kg bodyweights, respectively, based on rice consumption. Therefore, the sum of the estimated weekly intake for Pb, Zn, and Cu are 23.9, 808.8, 121.7 μg/week/kg bodyweight, respectively, considering both rice and fish consumption. The results of Zn and Cu are significantly lower than the permissible values suggesting no potential influences on human health of the two metals. However, it is not the same for Pb. Although the estimated intake value of Pb (23.9 μg/week/kg bodyweights) is slightly lower than the permissible value (25 μg/week/kg bodyweight), it will pose a risk on human health if too much fish is consumed. However, our study may not have sufficient power to investigate the heavy metal concentrations in other food, such as vegetables, meat, and so on. These diet intakes may be other routines of Pb intake, suggesting more attention should be paid to Pb contamination.

Heavy Metals in Local Environment

Heavy metals released into an ecosystem bio-magnifies at successively higher levels along the food chain, and cause potential adverse effects on the health of humans and wildlife. Evidence has shown positive correlations between Pb content in residents and their local environment (Baker *et al.* 1977; Järup 2003). In this study, the concentrations of Pb, Zn, and Cu in soil were 37.6–57.4 μg/g, 53.3–84.4 μg/g, and 14.1–28.4 μg/g, respectively, which were all within the quality standard established for soil used in agriculture production, according to the currently effective standard in China (MEP and AQSIQ of China 1995) (Table 4). In addition, the baseline concentration was employed to assess the pollution status of heavy metals in this area (Dudka *et al.* 1995; Meng and Li 1995). And the baseline concentrations of Pb, Zn, and Cu in soil were calculated as 39.4 μg/g, 196.5 μg/g, and 33.8 μg/g, respectively, by using the background values of elements in Jilin Province provided by Meng and Li (1995). According to the results, the concentrations of Zn and

Table 4. Concentrations of Pb, Zn, and Cu in local environment (mean ± SD) and comparison with the standard values.

Values found in this study			Standard values
Paddy soil (μg/g) N = 63	Pb	47.0 ± 4.5	300 μg/g of Pb (MEP& AQSIQ of China 1995)
	Zn	68.0 ± 6.4	250 μg/g of Zn (MEP & AQSIQ of China 1995)
	Cu	20.6 ± 3.4	100 μg/g of Cu (MEP & AQSIQ of China 1995)
Irrigation water from second Songhua River (μg/L) N = 12	Pb	15.1 ± 0.2	50 μg/L of Pb (MEP & AQSIQ of China 2002)
	Zn	28.5 ± 0.6	65 μg/L of Pb (USEPA 1999)
	Cu	6.7 ± 0.2	10 μg/L of Pb (WHO 1995)
Water from Chagan Lake (μg/L) N = 12	Pb	3.8 ± 0.2	1000 μg/L of Zn (MEP & AQSIQ of China 2002)
	Zn	24.8 ± 0.7	120 μg/L of Zn (USEPA 1999)
	Cu	5.9 ± 0.3	1000 μg/L of Cu (MEP & AQSIQ of China 2002) 9 μg/L of Cu (USEPA 1999)

N: number of samples.

Cu in all samples were lower than the baseline concentration while Pb in most soil samples was greater than the baseline concentration. It has been well documented that grain and vegetables are likely to accumulate toxic metals from agriculture soil in comparison to control sites (Abdullabi *et al.* 2009). This result suggests Pb control in agriculture soil should be of concern in the study area despite that it was within the standard value.

The mean concentrations of Pb, Zn, and Cu in the water for irrigation from the Second Songhua River were 15.1 μg/L, 28.5 μg/L, and 6.7 μg/L, respectively; and those from Chagan Lake were 3.8 μg/L, 24.8 μg/L, and 5.9 μg/L, respectively. Lu *et al.* (2009) reported similar concentrations in the same river as 4.4 μg/L, 25.4 μg/L, and 3.9 μg/L for Pb, Zn, and Cu, respectively. The heavy metal concentrations obtained from water were lower than the water quality standard established for water used as secondary centralized drinking water source, wintering grounds, and migration channels for fish and other fishing and swimming area waters, according to the currently effective standard in China (GB3838-2002) (MEP and AQSIQ of China 2002). In addition, the mean concentration of Pb was lower than the criteria maximum concentrations (CMC) established for Pb (65 μg/L) by the U.S. Environmental Protection Agency (USEPA 1999), the mean concentrations of Zn and Cu were lower than the criterion continuous concentration (CCC) values established for Zn (120 μg/L) and Cu (9 μg/L) by the same authority. The European Union has set the maximum value for Pb in drinking water as 25 μg/L by December 2003 and 10 μg/L by December 2013 for further protection of human health (Zaida *et al.* 2007). The World Health Organization has set the maximum safe limits for Pb in drinking water of 10 μg/L (WHO 1995). These results imply the surface water in the area is suitable for production but necessary preventive measures should be emphasized when it is used for drinking water.

CONCLUSIONS

The present study measured the concentrations of Pb, Zn, and Cu in the residents' scalp hair, diet, and the local environment in the Qianguo Irrigation Area, a long-term irrigation area downstream of the Second Songhua River, Northeast China. The principal conclusions are summarized as follows:

The average concentrations of Pb, Zn, and Cu in hair were 85.9 ± 51.1, 174.0 ± 31.1, and 6.7 ± 4.4 μg/g, respectively. Drinking habits significantly influenced the accumulation of Pb in scalp hair. The smokers tend to accumulate more toxic elements (Pb) and less nutrient elements (Zn and Cu) than non-smokers, but the differences were not significant ($p > .05$). No significant differences were found in contents of Pb, Zn, and Cu in scalp hair of residents with different age, and gender ($p > .05$).The Zn concentrations in hair are height-related but no significant correlation was found between other metals and height or weight. In general, the metals' concentrations in most of the food and the local environment were within China's standards. However, owing to the known effects of these contaminations on human health, more attention should be paid for public health Pb control in agriculture soils and in the drinking water of the study area.

ACKNOWLEDGMENT

This research took place under the auspices of the National Natural Science Foundation of China (No. 41101470), the Special S&T Project on Treatment and Control of Water Pollution (2012ZX07201004), and the Knowledge Innovation Programs of Chinese Academy of Sciences (No. KZCX2-YW-Q06-03).

REFERENCES

Abdullabi MS, Uzairu A, and Okunola OJ. 2009. Quantitative determination of heavy metal concentrations in onion leaves. Int J Environ Res 3(2):271–4

Afridi HI, Dermot B, Kazi TG, *et al.* 2011. Evaluation of essential trace and toxic elements in scalp hair samples of smokers and alcohol user Hhypertensive patients. Biol Trace Elem Res 143:1349–66

Afridi HI, Kazi TG, Brabazon D, *et al.* 2012. Interaction between zinc, cadmium and lead in scalp hair samples of Pakistani and Irish smokers Rheumatoid Arthritis subjects with related to controls. Biol Trace Elem Res 148:139–47

AQSIQ of China (Administration of Quality Supervision, Inspection and Quarantine). 2001. Safety Qualification for Agricultural Product for Non-Environmental Pollution Aquatic Products (GB 18406.4-2001), p 5. China Standards Press, Beijin, China (in Chinese)

Baig JA, Kazi TG, Shah AQ, *et al.* 2011. Determination of arsenic in scalp hair samples from exposed subjects using microwave-assisted digestion with and without enrichment based on cloud point extraction by electrothermal atomic absorption spectrometry. AOAC Int 94(1):293–9

Baker Jr EL, Hayes CG, Landrigan PJ, *et al.* 1977. A nationwide survey of heavy metal absorption in children living near primary copper, lead, and zinc smelters. Am J Epidemiol 106(4):261–73

Barman S and Lal M. 1994. Accumulation of heavy metals(Zn, Cu, Cd and Pb) in soil and cultivated vegetables and weeds grown in industrially polluted fields. J Environ Biol 15(2):107–15

CAC (Codex Alimentarius Commission). 2010. Codex General Standard for Contaminants and Toxins in Food and Feed (First adopted in 1995 and amended in 2010), CODEX STAN 193-1995. Geneva, Switzerland

Doğan-Sağlamtimur N and Kumbur H. 2010. Metals (Hg, Pb, Cu, and Zn) bioaccumulation in sediment, fish, and human scalp hair: A case study from the city of mersin along the southern coast of Turkey. Biol Trace Elem Res 136(1):55–70

Dudka S, Ponce-Hernandez R, and Hutchinson TC. 1995. Current level of total element concentrations in the surface layer of Sudbury's soils. Sci Total Environ 162(2–3):161–71

EU (European Union). 2008. Commission Regulation for Maximum Levels of Certain Contaminants in Foodstuffs, No. 629/2008. Brussels, Belgium

Feng QY, Suzuki A, and Hisashige A. 1997. Trace element contents in hair of residents from Harbin (China), Medan (Indonesia), and Tokushima (Japan). Biol Trace Elem Res 59(1–3):75–86

Gerhardsson L and Lundh T. 2010. Metal concentrations in blood and hair in pregnant females in Southern Sweden. J Environ H 72(6):37–41

Gorell JM, Johnson CC, Rybicki BA, *et al.* 1999. Occupational exposure to manganese, copper, lead, iron, mercury and zinc and the risk of Parkinson's disease. Neurotoxicology 20(2–3):239

Gupta S, Nayek S, Saha RN, *et al.* 2008. Assessment of heavy metal accumulation in macrophyte, agricultural soil, and crop plants adjacent to discharge zone of sponge iron factory. Environ Geol 55(4):731–9

Hauser G, Vienna A, Wolfsperger M, *et al.* 1999. Milk consumption, smoking and lead concentration in human hair. Collegium Antropologicum 23(2):433–6

Järup L. 2003. Hazards of heavy metal contamination. Brit Med Bull 68(1):167–82

Lin CY, He MC, Zhou YX, *et al.* 2008. Distribution and contamination assessment of heavy metals in sediment of the Second Songhua River, China. Environ Monit Assess 137:329–42

Liu XJ, Cheng JP, Song YL, *et al.* 2008. Mercury concentration in hair samples from Chinese people in coastal cities. J Environ Sci 20(10):1258–62

Lu JL, Hao LB, Zhao YY, *et al.* 2009. Contents and potential ecological risk of heavy metals in middle and lower reaches of Second Songhua River. Environ Sci Tech 32(5):168–72 (in Chinese with English abstract)

Mehra R and Juneja M. 2004. Atomic absorption spectrophotometric determination of Pb, Cd, Cu, Mn, Cr, Ni and Fe levels in human hair. Influence of age, hair colour and smoking habit. J Indian Chem Soc 81(4):349–50

Mehra R and Juneja M. 2005. Elements in scalp hair and nails indicating metal body burden in polluted environment. J Sci Ind Res 64(2):119–24

Meng XX and Li SZ. 1995. Background Value of Soil Elements in Jilin Province, p 41. Science Press, Beijing, China (in Chinese)

Meng ZQ. 1998. Age- and sex-related differences in zinc and lead levels in human hair. Biol Trace Elem Res 61(1):79–87

MEP (Ministry of Environmental Protection) and AQSIQ (Administration of Quality Supervision, Inspection and Quarantine) of China. 2002. Environmental Standards for Surface Water (GB 3838-2002). China Standards Press, Beijing, China (in Chinese)

MEP and AQSIQ of China. 1995. Environmental Standards for Soils (GB 15618-1995). China Standards Press, Beijing, China (in Chinese)

MOH (Ministry of Health) and SAC (Standardization Administration of China) of China. 2005. Maximum Levels Of Contaminants in Foods (GB2762-2005). China Standards Press, Beijing, China (in Chinese)

MOH of China. 1991. Tolerance Limit of Zinc In Food (GB13106-91). China Standards Press, Beijing, China (in Chinese)

MOH of China. 1994. Tolerance Limit of Copper in Food (GB15199-94). China Standards Press, Beijing, China (in Chinese)

Olmedo P, Pla A, Hernandez AF, *et al.* 2010. Validation of a method to quantify chromium, cadmium, manganese, nickel and lead in human whole blood, urine, saliva and hair samples by electrothermal atomic absorption spectrometry. Anal ChimActa 659(1–2): 60–7

Qu CS, Sun K, Wang SR, *et al.* 2012. Monte Carlo simulation-based health risk assessment of heavy metal soil pollution: A case study in the Qixia Mining Area, China. Hum Eco Risk Assess 18:733–50

Razagui IBA and Ghribi I. 2005. Maternal and neonatal scalp hair concentrations of zinc, copper, cadmium, and lead-Relationship to some lifestyle factors. Biol Trace Elem Res 106(1):1–27

Rivai IF. 2001. Heavy metals in human hair related to age groups and automotive pollution levels of Bandarlampung City, Indonesia. B Environ Contam Tox 66(4):443–8

Selevan SG, Rice DC, Hogan KA, *et al.* 2003. Blood lead concentration and delayed puberty in girls. N Engl J Med 348(16):1527–36

Sturaro A, Parvoli G, Doretti L, *et al.* 1994. The influence of color, age, and sex on the content of zinc, copper, nickel, manganese, and lead in human hair. Biol Trace Elem Res 40(1): 1–8

Torrente M, Colomina MT, and Domingo JL. 2005. Metal concentrations in hair and cognitive assessment in an adolescent population. Biol Trace Elem Res 104(3):215–21

Tuthill R. 1996. Hair lead levels related to children's classroom attention-deficit behavior. Arch Environ H 51(3):214–20

Unkiewicz-Winiarczyk A, Gromysz-Kalkowska K, and Szubartowska E. 2009. Aluminium, cadmium and lead concentration in the hair of tobacco smokers. Biol Trace Elem Res 132(1–3):41–50

USEPA (US Environmental Protection Agency). 1999. National Recommended Water Quality Criteria-Correction (EPA 822-Z-99–001). Office of Water, Washington, DC, USA

Wang T, Fu J, Wang YW, *et al.* 2009. Use of scalp hair as indicator of human exposure to heavy metals in an electronic waste recycling area. Environ Pollut 157(8–9):2445–51

Wang XL, Sato T, Xing BS, *et al.* 2005. Health risks of heavy metals to the general public in Tianjin, China via consumption of vegetables and fish. Sci Total Environ 350(1–3): 28–37

WHO (World Health Organization). 1995. Trace Elements in Human Nutrition and Health. Geneva, Switzerland

Yeganeh M, Afyuni M, Khoshgoftarmanesh AH, *et al.* 2012. Health risks of metals in soil, water, and major food crops in Hamedan Province, Iran. Hum Eco Risk Assess 18:547–68

Zaida F, Chadrame S, Sedki A, *et al.* 2007. Lead and aluminium levels in infants' hair, diet, and the local environment in the Moroccan city of Marrakech. Sci Total Environ 377(2–3):152–8

Zhang L, Zhang L, and Wang QC. 2008. A preliminary study on the route of mercury exposure among residents living in Songyuan area. Stud Trace Elem H 25(3):30–2 (in Chinese with English abstract)

Zhu H, Yan BX, Cao HC, *et al.* 2012. Risk assessment for methylmercury in fish from the Songhua River, China: 30 years after mercury-containing wastewater outfalls were eliminated. Environ Monit Assess 184:77–88