Environ Monit Assess (2019) 191: 443
https://doi.org/10.1007/s10661-019-7592-z

# Distribution characteristics and influencing factors of heavy metals in scalp hair of Huainan urban residents

**Fengman Fang · Yue Wang · Zhe Zhu · Youru Yao · Yuesheng Lin · Jianfei Wang**

Received: 30 November 2018 / Accepted: 4 June 2019 / Published online: 16 June 2019


**Abstract** In order to explore the level of heavy metal pollution in human hair of residents in Huainan City and provide theoretical guidance for prevention and control of heavy metal pollution, human hair samples from 174 residents in Huainan City were collected so that heavy metal (Cr, Cu, Pb, Zn, As, and Fe) concentrations in scalp hair could be tested, and meanwhile their relationship with sex, age, and spatial distribution characteristics could be explored as well. According to the final analysis, the average concentration of Cr, Pb, Cu, Fe, Zn, and As in human hair amounted to 1.56, 6.41, 14.96, 31.13, 166.54, and 1.07 mg/kg. The highest average of Cr and Pb contents in human hair occurred in the area of Xiejiaji District; Fe, Zn, and Hg were in Datong District; and Cu and As were in Panji District respectively. Overall, the lowest risk of heavy metal exposure existed in Tianjia'an District. Heavy metal content in hair varied across sexes and ages. Pb concentration in hair would decrease as age increased. The highest Pb concentration appeared in children between ages 0 and 10, the amount of which was significantly different from that in other age groups; hence, children appear to be more susceptible to Pb pollution than other ages. Contents of Cr, Fe, Zn, and As in hair would also increase with age; Fe content in hair was particularly correlated with age. The contents of Cr, Pb, Fe, and As in men's hair were higher than those in women's, whereas the case of Cu and Zn was just the opposite. There were significant differences between sexes concerning the contents of Cr, Cu, and As, and a highly significant difference about Zn between sexes as well. These results indicated that the contents of heavy metal in residents' hair would be closely related to the features of the local environment and population.

**Keywords** Human scalp hair · Heavy metal · Distribution characteristics · Age · Sex

F. Fang · Y. Wang · Y. Yao · Y. Lin · J. Wang
School of Geography and Tourism, Anhui Normal University, Wuhu 241003, China

F. Fang (✉)
Anhui Key Laboratory of Natural Disaster Process and Protection Research, Anhui Normal University, Wuhu 241003, China
e-mail: ffm1974@mail.ahnu.edu.cn

Z. Zhu
Anhui Vocational College of City Management, Hefei 231635, China

## Introduction

Various elements would be accumulated in human hair through blood circulation in a highly stable manner (Cihan and Yıldırım 2011). Compared with blood and urine, human hair samples are less invasive and easier to collect, transport, and store (Bencko 1995). Hair can reflect past elemental exposure, indicate hair growth, and show levels of heavy metal exposure over extended periods (Chojnacka et al. 2012; Liang et al. 2017; Jiang et al. 2017). International organizations such as the World Health Organization have named hair as an ideal material for evaluating heavy metal loads in the human body (Samanta et al. 2004; Mehra et al. 2010). Thus, human scalp hair has received considerable attention recently in bio-monitoring to measure individuals' heavy metal exposure (Bencko 1995; Wongsasuluk et al. 2018; Zhu et al. 2018; Varrica et al. 2018).

Previous studies have focused on human hair's heavy metal content (Wang et al. 2017a, b; Kwaansa-Ansah et al. 2019), background values (Carneiro et al. 2011), influencing factors (Skalnaya et al. 2014; Zhou et al. 2017), environmental exposure indicators (Baran and Wieczorek 2013; María et al. 2017), and clinical applications (Henriques et al. 2019). Some researches on heavy metals in human hair in mining areas or disease-prone regions have been carried out in China. The heavy metal content in human hair is influenced by many factors, and a variety of conclusions have been drawn by different scholars. However, the influencing mechanism behind the heavy metal content in human hair still needs further exploration. This study therefore will take residents' hair in four districts of Huainan as the samples for detailed discussion. The contents and spatial distribution features of Pb, Cu, Zn, Cr, As, and Fe in hair of Huainan City residents have been thoroughly analyzed with statistical methods, so as to reveal heavy metal exposure levels and explore the corresponding relevance with the age, sex, and spaces. The purpose of this study is to provide a scientific insight into the effective way of preventing and controlling heavy metal pollution and thus protecting residents' health better in the future.

## Materials and methods

### Study area

Huainan City, located in the mid-northern part of Anhui Province, is a typical coal-resources-based city. Documented coal field reserves amount to 18 billion tons in this area accounting for 70% of the coal storage in Anhui Province and 32% in eastern China. Coal mining activities first began in Huainan 100 years ago, there used to be many active open-cast and underground mines, but meanwhile abandoned coal mines, natural coal fires, and overburden dumps could be found all around the city (Zheng et al. 2015; Lin et al. 2017).

Huainan City has four districts including Tianjia'an (TJA), Panji (PJ), Xiejiaji (XJJ), and Datong (DT), in which the TJA district is the city's administrative and economic center, and the traffic here is much busier than that of in other districts. While in XJJ and PJ districts, there are abundant coal resources and coal mining has become the major industrial activity. As for DT district, it is a suburban area with predominantly agricultural production as the pillar industry.

### Sample collection

For this study, 174 hair samples were collected from four districts in Huainan City in 2015. Because the accumulation of heavy metals in the hair would be a long-term process, hair dyeing and perming might have a certain kind of interference. As for the sample collection, there are a series of requirements to meet the experimental needs. All the sample hairs must be healthy, have no history of taking drugs in a short period of time, have not been permed and other hairdressing treatments, and are permanent residents living in Huainan City for more than 3 years (Wongsasuluk et al. 2018). The hair samples were collected from residents of different ages and sexes. About 2–3 g of hair were collected near the scalp by using a pair of stainless steel scissors when people cut their hair (Pereria et al. 2004). Then, the samples were stored in a unified configuration of clean bags with different labels. Then, a form would be filled out to record relevant information such as the donor's age, sex, lifestyle, and residence (Table 1).

### Sample processing

Hair samples used for the study should be thoroughly cleaned with grade acetone four times, then rinsed three times with ultrapure water to remove any exogenous impurities (Pereria et al. 2004). The washed hair samples were dried at 70 °C in the oven for a constant

**Table 1** Donor's information

| Item | Group | Number | Item | | Number |
|---|---|---|---|---|---|
| Age | 0~10 | 53 | Residence | Datong | 35 |
| | 11~20 | 45 | | Panji | 37 |
| | 21~30 | 10 | | Tianjia'an | 63 |
| | 31~40 | 19 | | Xiejiaji | 39 |
| | 41~50 | 23 | Sex | | |
| | 51~60 | 10 | | Male | 93 |
| | 61~70 | 10 | | Female | 81 |
| | > 70 | 4 | | | |

weight. The dried samples then cut into segments with the length of about 2–4 mm each and properly stored before further analysis.

A total of 0.4 g hair samples were soaked in 10 ml nitric acid and 2 ml perchloric acid overnight. The next day, the samples were heated on a hot plate until they were almost dry (i.e., until the solution became transparent). After cooling, samples were rinsed with 2.5% nitric acid and diluted to 50 mL distilled water before being analyzed for heavy metals via an inductively coupled plasma–optical emission spectrometer (ICP-OES, PE, 7000DV).

### Quality control

All laboratory utensils were pre-soaked in 10% $HNO_3$ for over 24 h and thoroughly rinsed with ultrapure water before use. One-quarter (25%) of the hair samples selected randomly were analyzed three times to ensure the precision and accuracy. Each batch of experiments had three blank samples. The analysis-standard material of plant and human hair component (GBW07601) measured by ICP-OES demonstrated good accuracy, with percent recoveries between 80 and 120% (Table 2).

## Results and discussion

### Levels of heavy metals in Huainan City residents' hair

The range and mean values of heavy metals in Huainan City residents' hair are shown in Table 3. The average concentration of Cr, Pb, Cu, Fe, Zn, and As in hair was as follows: 1.56, 6.41, 14.96, 31.13, 166.54, and 1.07 mg/kg. Among the six heavy metals, Pb demonstrated relatively higher dispersion as indicated by coefficient of variation (CV) values. The other five elements varied moderately, while indicating significant differences of heavy metal distribution in Huainan City residents' hair.

Compared with the element content in other countries or regions, the elements in Huainan City residents' hair were moderately in excess. Among them, the average content of Fe was only lower than that in Inner Mongolia; Baotou; and North Carolina, USA. The average content of Zn in human hair was lower than that in Inner Mongolia; Baotou; Chongqing; and North Carolina, USA. Zn and Fe contents in human hair were related to nutrition levels; high-protein food intake such as meat, eggs, and dairy products may increase the contents of Zn and Fe (Pan and Li 2015). In recent years, Huainan City residents' nutrition levels and dietary habits have been greatly improved which led to higher Fe and Zn levels in their hair. The average As content in hair was only lower than that in Turkey and North Carolina, USA, because the continual development of Huainan City's coal industry, coal-fired power consumption is large.

### Spatial distribution features of heavy metals in Huainan City urban residents' hair

The average heavy metal content in Huainan City showed the following spatial distribution patterns: for Pb, XJJ District > PJ District > DT District > TJA District; for Cu, PJ District > XJJ District > DT District > TJA District; for Zn, DT District > XJJ District > PJ District > TJA District; for As, PJ District > DT District > XJJ District > TJA District (Fig. 1).

The respective contents of Cr, Pb, Cu, Zn, and As in human hair in the TJA District was the lowest, and Fe content was also quite low. The contents of heavy metal in the TJA district were also low. Significant differences were observed in Cr and Fe in hair among different areas of Huainan City, but the distinctions among the other four heavy metals in hair were not obvious across different regions. There existed a clear diversity of Cr in Tianjia'an region compared with other places like Datong, Panji, and Xiejiaji ($P < 0.01$), and the content was much lower than that in the other three regions. Fe content varied a lot

**Table 2** The CRM data of heavy metals analyze by ICP-OES (mg/kg)

| | As | Cr | Cu | Fe | Pb | Zn |
|---|---|---|---|---|---|---|
| Standard value | 0.28 | 0.37 | 10.6 | 54 | 8.8 | 190 |
| Measured value | 0.24 | 0.35 | 11.98 | 58.86 | 7.04 | 228.00 |
| Recovery rate (%) | 85.71 | 94.59 | 113.02 | 109.00 | 80.00 | 120.00 |

**Table 3** Heavy metal content in human hair in different countries and areas (mg/kg)

| | | Cr | Pb | Cu | Fe | Zn | As |
|---|---|---|---|---|---|---|---|
| Huainan City | Range | 0.02–1.96 | 0.23–58.49 | 3.70–63.94 | 0.92–145.56 | 52.23–370.01 | 0.20–4.47 |
| | Mean | 1.56 | 6.41 | 14.96 | 31.13 | 166.54 | 1.07 |
| | CV (%) | 71.80 | 115.76 | 61.50 | 67.75 | 46.20 | 57.01 |
| North Carolina (Kumakli et al. 2017) | Mean | 1.41 | 0.868 | 25.9 | 70.5 | 349 | 1.53 |
| Inner Mongolia, Baotou (Pan and Li 2015) | Mean | 2.41 | 2.36 | 9.07 | 62.83 | 281.67 | 0.045 |
| Shanghai (Wang et al. 2017a) | Mean | / | 1.64 | 11.42 | / | 121.20 | / |
| Chongqing (He et al. 2017) | Mean | / | 42.8 | 24.3 | / | 209.6 | / |
| Pearl River Delta region (China) (Li et al. 2014) | Mean | / | 8.97 | 28.49 | / | 136.65 | 0.75 |
| Turkey (Cihan and Yıldırım 2011) | Mean | 0.93 | 5.10 | 15.75 | 25.01 | 109.76 | 1.14 |
| America (DiPietro et al. 1989) | Mean | 0.15 | 2.43 | 15.7 | 9.16 | 150 | 0.22 |
| Tianjin (Wang et al. 2017b) | Mean | 2.65 | 13.69 | 16.82 | / | 197.29 | / |
| Chinese resident normal hair content[a] | | 1.21 ± 0.63 | 7.1 ± 3.2 | 11.0 ± 3.5 | | 130 ± 30 | |

[a] Standards from Chinese Trace Elements Scientific Society (H/ZWY03-2005, H/ZWY01-2007)

between Datong and Xiejiaji ($P < 0.05$); it was much higher in Datong residents' samples than in those from Xiejiaji. The highest average contents of Fe and Zn were discovered in Datong given its centuries-long history of coal mining. Heavy metal accumulation in the environment has been caused by area production and a sewage petrochemical machinery plant. At the same time, Datong is a rural area where most residents use coal for cooking and heating, resulting in high Fe and Zn levels. Celik et al. (2009) also pointed out that when the Fe and Mn values of the hair samples collected from the industrial region were compared with the data from both the city center and countryside (ANOVA), the differences would be quite meaningful and significant. The highest average Cu and As levels appeared in Panji, which is the main coal mining base in Huainan City. There, As content in human hair was mainly related to coal combustion; it increased obviously in areas where As coal was burned (Zhong et al. 1999). The PJ district invested greatly in the Pingwei power plant, and Cu levels in hair displayed the extent of atmospheric pollution. Studies have shown that long-term exposure to smoke and dust would make Cu levels in human hair high (Xu and Zhou 1994). Therefore, people's daily activities should be far away from the mining environment. In daily life, the use of coal fuel should be reduced families near the mine had better keep the doors and windows closed to prevent the pollution of dust. For children, it is necessary to wear masks and wash hands and faces in time.

## Analysis of influencing factors

*Gender differences in heavy metal content of human hair* Heavy metal content in human hair from Huainan City differed a lot between genders (Table 4). Zn and Cu levels in men's hair were lower than those in women's, whereas the contents of Cr, Pb, Fe, and As were higher. Cr, Cu, and As contents also varied a lot between men and women ($P < 0.05$), while Zn demonstrated a highly distinction between genders ($P < 0.01$). Tamburo et al. (2016) found that Zn content in adolescent girls' hair was significantly higher than that in boys. Xu et al. (1999) reported that Cr content in different-aged male adolescent groups in Yulin, Guangxi was higher than that in a female group, which can be taken as a proof to the study. Since the social division of labor between men and women varies a lot, men are more likely to be engaged in jobs that are easily exposed to Cr elements than women, such as non-ferrous metal mining and electroplating industries (Tian et al. 2016). Coal mining is a major industry in Huainan City; so many men might take the job concerning mining activities, resulting in higher levels of Cr in men's hair than in women's. Shi et al. (1999) reported that Cu in girls' hair in Changchun was more than that of boys; this may be due to sex-based developmental and metabolic differences. Li et al. (2016) reported that As in male residents' hair in a mining area of Guangxi was much more than that of females. As with Cr, daily occupational exposure can affect its content in different sexes. Therefore, men

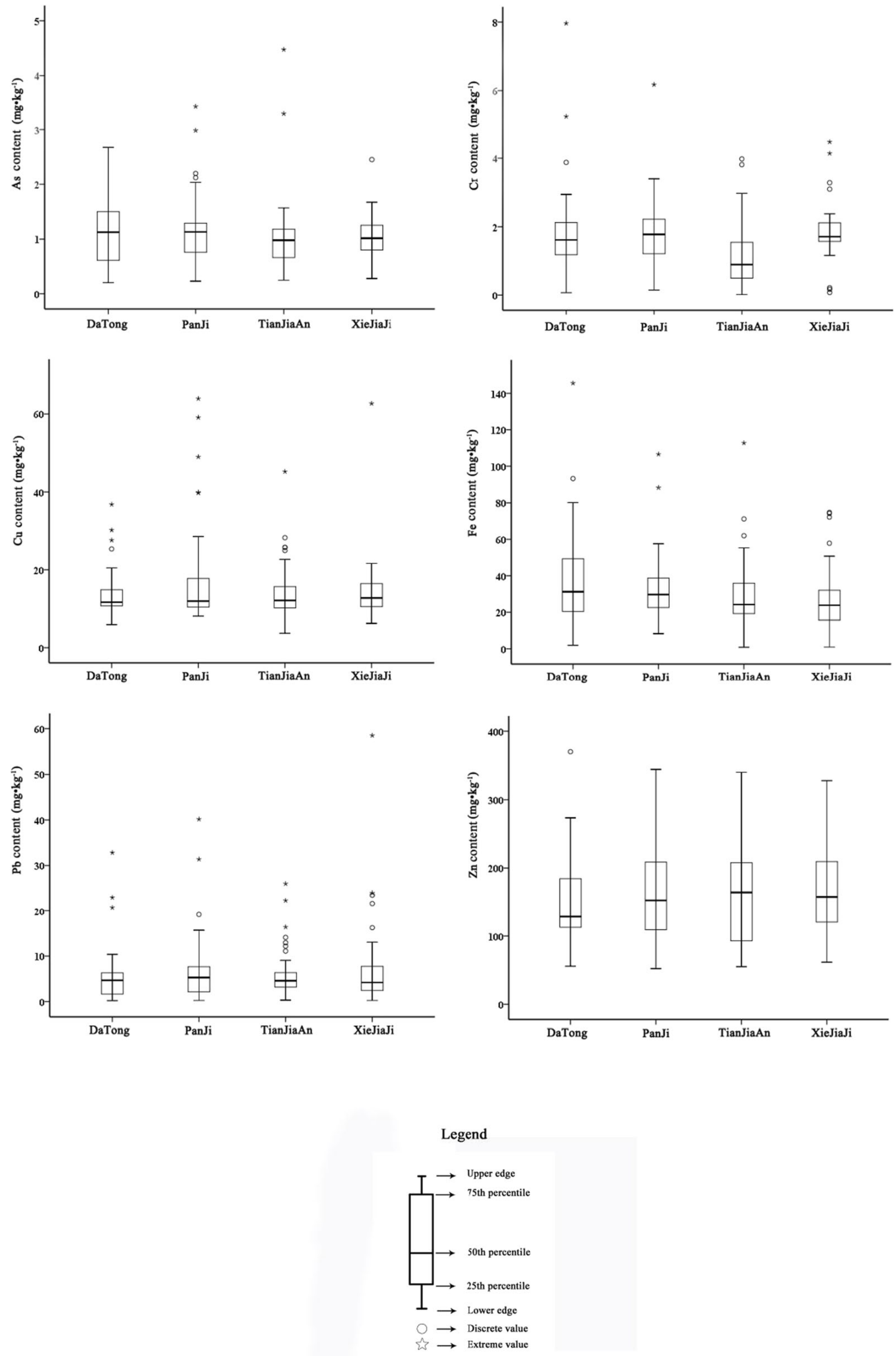


**Fig. 1** Heavy metal contents in residents' hair in different regions of Huainan City

**Table 4** Heavy metal content in human hair in different sexes (mg/kg)

| | | Cr | Pb | Cu | Fe | Zn | As |
|---|---|---|---|---|---|---|---|
| Male | $n = 93$ | 1.74 Aa | 6.94 Aa | 13.5 Aa | 32.58 Aa | 147.8 Aa | 1.18 Aa |
| Female | $n = 81$ | 1.36 Ba | 5.81 Aa | 16.64 Ba | 29.47 Aa | 188.06 Bb | 0.95 Ba |

Uppercase letters and lowercase letters denote significance at the $P = 0.05$ and $P = 0.01$ levels, respectively

should minimize skin exposure in areas contaminated with Cr and As.

There is significantly different of Pb levels between men and women in Huainan City residents' hair ($P < 0.05$), perhaps because men have more opportunities to encounter Pb. He et al. (2017) also found that Pb level was higher in boys than in girls. Fe is an essential nutrient for the human body and plays an important role in human health. Men are more likely to take work in labor-intensive industries and have better appetites than women; thus, they probably ingest more Fe with food. In addition, adult women lose Fe during menstruation (Han et al. 2015), resulting in lower Fe content in women's hair compared with men. However, no definite disparities can be found in Fe content between both sexes in Huainan City ($P > 0.05$).

*Effects of different ages on heavy metal content in hair* The heavy metal content in human hair of different-aged residents in Huainan City is presented in Fig. 2. Pb content in hair decreased as age increased. The change in Cu with age growth was not obvious. The incidence of Cr, As, Fe, and Zn in the hair showed a tendency to increase with age (Fig. 2). The average contents of Cr, As, Fe, and Zn were in the highest degree among the 70-year-old group, amounting to 1.94 mg/kg, 1.50 mg/kg, 40.98 mg/kg, and 190.48 mg/kg respectively. Average Cr, As, and Fe contents in the 11–20 age group was at the lowest: 1.41 mg/kg, 0.95 mg/kg, and 26.12 mg/kg respectively. The results of the correlation analysis between human heavy metal content and age have listed in Table 5. The degree of fit between age and Cr content in hair was rather low ($r = 0.115$, $P > 0.05$), and the $t$ test showed there was no significant difference of Cr among the different age groups. The degree of fit between As content in hair and different ages was quite high, with a fitting coefficient of 0.221 ($P < 0.01$). The content of As increased with age, but no clear difference appeared among age groups. Wang et al. (2012) reported that hair's As content increased with age in Sihong County, Jiangsu Province, with a positive correlation between As content and age ($P < 0.05$). After As enters the human body, it combines with two sulfur bonds of sulfur-containing amino acids in the keratin in hair (Lin et al. 2001). Metabolism of As in hair is going through a long and stable process; thus, the element accumulates continuously in hair as age increases. Fe content in hair showed a similar trend of increasing with age along with a significant correlation and fitting coefficient of 0.199 ($P < 0.01$).

The average content of Zn in the 0–10 age group was the lowest, with an average content of 139.85 mg/kg. The degree of fit between Zn content in hair and age was quite high, with a fitting coefficient of 0.149 ($P < 0.05$). Some scholars (Dong and Cai 1999) agree that Zn content in hair increases with age; it is affected endogenously, mainly by daily intake of foods containing Zn such as animal offal, fish, shrimp, shellfish, beef, mutton, eggs, nuts, and so on. While children are growing rapidly, they need to consume large amounts of variety food, a simple diet or insufficient protein intake may result in Fe and Zn deficiency in infants and children (Tang et al. 1999). Fe and Zn contents in hair increased as age increased alongside the accumulation of trace elements in the body and a balanced diet.

Pb content in hair declined as age increased. The highest Pb levels appeared in the 0–10 age group with an average content of 7.23 mg/kg; the lowest average content appeared in individuals older than 70 (average content of 2.93 mg/kg). The degree of fit between Pb in hair and age was rather low, with a fitting coefficient of −0.137 ($P > 0.05$). Most scholars believe Pb content in hair decreases as age increases, particularly because the body's ability to ingest Pb decreases with age (Lockeretz 1973). In addition, automobile exhaust contains high levels of alkyl Pb. Because children are not as tall as adults, their respiratory region is just in correspondence with the automobile exhaust collection zone (Qian et al. 2013), thus causing more exhaust intake. Certain bad habits, such as placing toys, pencils, or their hands into their mouths after playing, may contribute to childrens's' Pb intake. Infants' slow metabolism and

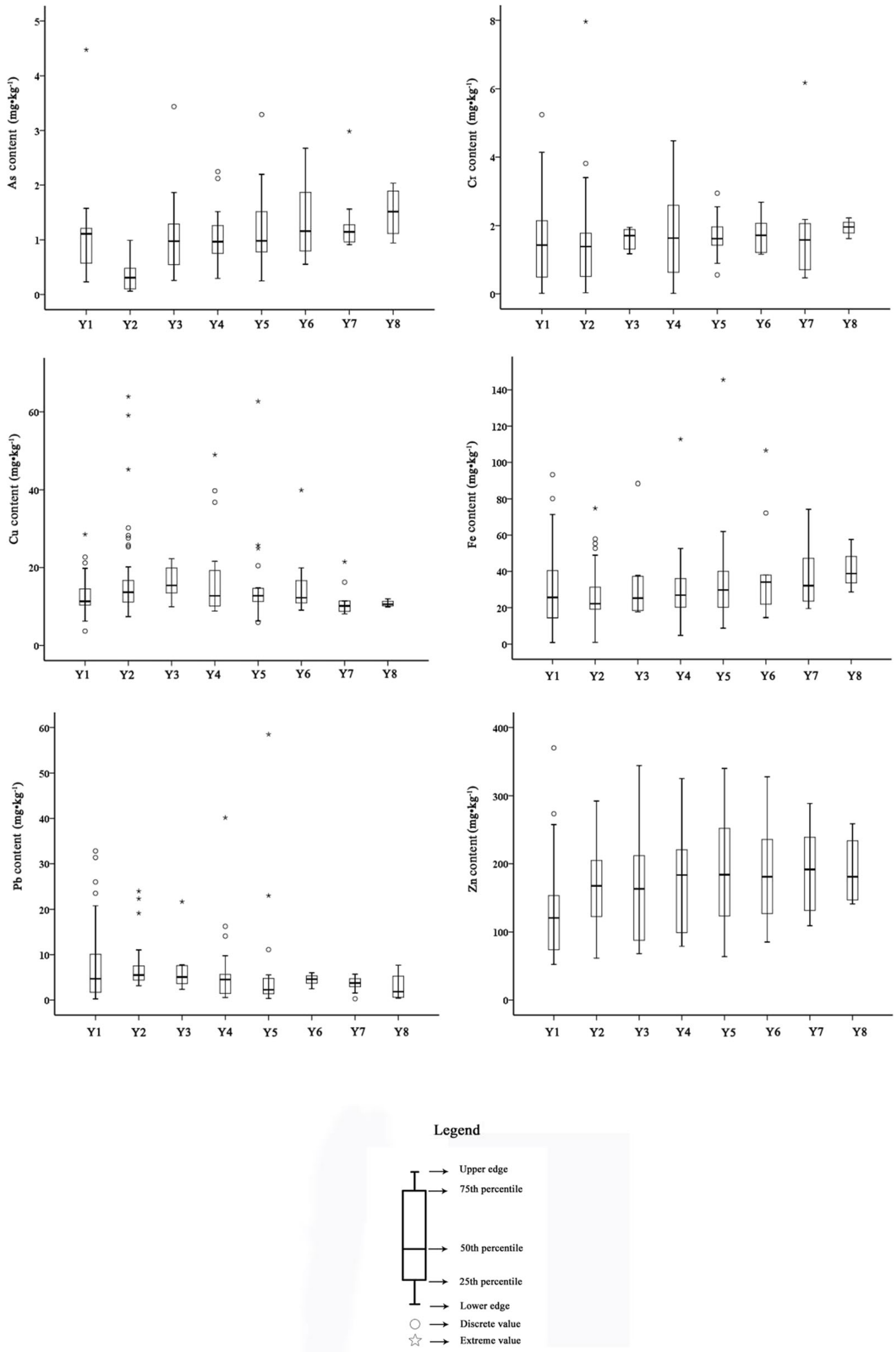


**Fig. 2** Heavy metal contents in residents' hair in different age groups from Huainan City

**Table 5** Correlation analysis between heavy metal content in hair with age in Huainan City

| Element | Cr | Pb | Cu | Fe | Zn | Hg | As |
|---|---|---|---|---|---|---|---|
| *r* value | 0.115 | − 0.137 | 0.014 | 0.199** | 0.149* | 0.169* | 0.221** |
| *P* value | > 0.05 | > 0.05 | > 0.05 | < 0.01 | < 0.05 | < 0.05 | < 0.01 |

waste excretion also results in Pb accumulation in the body (Geng et al. 2002). All these factors lead to higher levels of Pb in children than in adults, which can be tested in the hair. The trend of Cu content with age is complex, and there is no obvious pattern. Cu content in children aged 0–10 years was significantly lower than in 11- to 20-year-olds, possibly due to the start of puberty (Wu et al. 1993). The degree of fit between Cu content in hair and residents' age was quite low ($r = 0.014$, $P > 0.05$). Dong and Cai (1999) reported that the Cu content of normal children in Shenzhen decreased gradually as age increased.

## Conclusion

(1). The average contents of Cr, Pb, Cu, Fe, Zn, and As in Huainan City residents' hair were as follows: 1.56 mg/kg, 6.41 mg/kg, 14.96 mg/kg, 31.13 mg/kg, 166.54 mg/kg, and 1.07 mg/kg, respectively. Compared with other regions and countries, Huainan City residents exhibited higher levels of Cr, Zn, and As. Each element's CV value exceeded 40%, indicating some differences in heavy metal distribution in Huainan City residents.

(2). Heavy metal content in hair differed in certain areas: the highest average contents of Cr and Pb was in the XJJ District; the highest average contents of Fe and Zn was in the DT District; and the highest average contents of Cu and As existed in the PJJ District. Pb generally showed a strong degree of variability, indicating that environmental exposure may have an impact on Pb. The lowest degree of variability was found in Zn, indicating little difference in hair as an essential human element. There were significant differences between Cr and Fe elements in various regions of Huainan City, but the other four heavy metals showed no obvious distinctions in hair from different regions.

(3). The heavy metal content in Huainan City residents' hair differed a lot by gender and age. The degree of Cr, Pb, Fe, and As contents in men's hair were higher than that in women, whereas Cu and Zn showed an opposite trend. Cr, Cu, and As demonstrated significant differences between sexes; sex-based differences in Zn were most significant. Heavy metal content across ages also differed: Pb in hair decreased as age increased, changes in Cu with age were not significant, and the other five elements exhibited the increasing contents with age. High levels of Pb appeared in children aged 0–10, indicating a significant difference compared with other age groups; this finding suggests that children are most susceptible to Pb pollution. Fe and Zn contents in hair were closely related with age, but the relationship between the other elements and age was not significant.

(4). The daily activity area of residents in Huainan City should be far away from the mining area. In daily life and work, they should pay attention to the protection work, especially those men working in Cr- and As-contaminated areas should be cautious of skin exposure. Heavy metal accumulation in the human body warrants continued attention to prevent heavy metal poisoning and to ensure public health safety.

**Funding information** The research was supported by The National Natural Science Foundation of China through Grant 41371480.

## References

Baran, A., & Wieczorek, J. (2013). Concentrations of heavy metals in hair as indicators of environmental pollution. *E3S Web of Conferences, 1*, 21005.

Bencko, V. (1995). Use of human hair as a biomarker in the assessment of exposure to pollutants in occupational and environmental settings. *Toxicology, 101*, 29–39.

Carneiro, M. F. H., Grotto, D., Batista, B. L., Rhoden, C. R., Jr., & Barbosa, F. (2011). Background values for essential and toxic elements in children's nails and correlation with hair levels. *Biological Trace Element Research, 144*, 339–350.

Celik, A., Abali, Y., Edgunlu, G., Uzunoglu, S., & Tirtom, V. N. (2009). Some heavy metal determination by ICP-OES in human scalp hair (in three different regions of Manisa). *Ekoloji, 19*, 71–75.

Chojnacka, K., Saeid, A., Michalak, L., & Mikulewicz, M. (2012). Effects of local industry on heavy metals content in human hair. *Polish Journal of Environmental Studies, 21*, 1563–1570.

Cihan, Y. B., & Yıldırım, S. Ö. (2011). A discriminant analysis of trace elements in scalp hair of healthy controls and stage-IIIB non-small cell lung cancer (NSCLC) patients. *Biological Trace Element Research, 144*, 272–294.

DiPietro, E. S., Phillips, D. L., Paschal, D. C., & Neese, J. W. (1989). Determination of trace elements in human hair. *Biological Trace Element Res earch, 22*, 83–100.

Dong, G. Q., & Cai, X. X. (1999). Comparison of zinc, copper, plumbum and cadmium in children hair of different ages. *Guangdong Trace Elements Science, 6*, 31–33 in Chinese.

Geng, Z. H., He, P., Jiang, H. M., Zhang, Q. L., Pan, J., & Hou, S. W. (2002). Analysis on variable tendency of human hair lead and zinc and correlation. *China Public Health, 18*, 78–79 in Chinese.

Han, W. Q., Wu, S. L., Lv, W., Jiang, L. I., Yin, Y. T., Zhang, Y., Zhang, P., Wang, R., Wang, Y. H., & Li, B. (2015). Detection of levels of Mn, Fe, Zn, Ca and Mg elements in hair of adults and their correlation with BMI. *Journal of Jilin University (Medicine Edition), 41*, 405–409 (in Chinese).

He, M. J., Li, Q., Wang, D. X., Zhao, J. Y., & Yang, T. (2017). Bioaccumulation and correlation of heavy metals in human hairs from urban and rural areas of Chongqing. *Environmental Sciences*. https://doi.org/10.13227/j.hjkx.201610030 in Chinese.

Henriques, M. C., Loureiro, S., & Fardilha, M. (2019). Exposure to mercury and human reproductive health: a systematic review. *Reproductive Toxicology, 85*, 93–103.

Jiang, Y. X., Chao, S. H., Liu, J. W., Yang, Y., Chen, Y. J., Zhang, A. C., & Cao, H. B. (2017). Source apportionment and health risk assessment of heavy metals in soil for a township in Jiangsu Province, China. *Chemosphere, 168*, 1658–1668.

Kumakli, H., Duncan, A. V., McDaniel, K., Mehari, T. F., Stephenson, J., Maple, L., Crawford, Z., Macemore, C. L., Babyak, C. M., & Fakayode, S. O. (2017). Environmental biomonitoring of essential and toxic elements in human scalp hair using accelerated microwave-assisted sample digestion and inductively coupled plasma optical emission spectroscopy. *Chemosphere, 174*, 708–715.

Kwaansa-Ansah, E. E., Armah, E. K., & Opoku, F. (2019). Assessment of total mercury in hair, urine and fingernails of small–scale gold miners in the Amansie West District, Ghana. *Journal of Health and Pollution, 9*, 190306.

Li, J. Q., Cen, D. Z., Huang, D. L., Li, X. F., Xu, J. J., Fu, S. L., Cai, R., Wu, X. C., Tang, M., Sun, Y., Zhang, J. R., & Zheng, J. F. (2014). Detection and analysis of 12 heavy metals in blood and hair sample from a general population of Pearl River Delta area. *Cell Biochemistry and Biophysics, 70*, 1663–1669.

Li, Y., Xiao, M., & Chen, F. M. (2016). Comparative analysis of arsenic content in hair between men and women in a mining area of Northwest Guangxi. *Journal of Guangxi Medical University, 38*, 1028–1029 in Chinese.

Liang, G., Pan, L. G., & Liu, X. H. (2017). Assessment of typical heavy metals in human hair of different age groups and foodstuffs in Beijing, China. *International Journal of Environmental Research and Public Health, 14*, 914–923.

Lin, K. F., Xu, X. Q., Paul, A., Xiang, Y. L., & Jin, X. (2001). Relationship between As contents of farmers' hair and of environment in As polluted area. *China Environmental Science, 21*, 440–444 in Chinese.

Lin, Y. S., Fang, F. M., Wu, J. Y., Zhu, Z., Zhang, D. L., & Xu, M. L. (2017). Indoor and outdoor levels, sources, and health risk assessment of mercury in dusts from a coal-industry city of China. *Human and Ecological Risk Assessment, 23*, 1028–1040.

Lockeretz, W. (1973). On the lead content of human hair (1871-1971). *Science, 178*, 69–70.

María, T. L. B., Irene, N. S., & Silvia, I. Á. (2017). Reference levels of trace elements in hair samples from children and adolescents in Madrid, Spain. *Journal of Trace Elements in Medicine and Biology, 43*, 113–120.

Mehra, R., Thakur, A. S., & Bhalla, S. (2010). Trace level analysis of chromium, manganese, cobalt and iron in human hair of people residing near heavy traffic area by biomonitoring. *International Journal of Pharma and Bio Sciences, 1*, 57–61.

Pan, Y., & Li, H. (2015). Trace elements in scalp hair from potentially exposed individuals in the vicinity of the Bayan Obo mine in Baotou, China. *Environmental Toxicology and Pharmacology, 40*, 678–685.

Pereria, R., Riberro, R., & Goncalves, F. (2004). Scalp hair analysis as a tool in assessing human exposure to heavy metals (S. Domingos mine, Portugal). *Science of the Total Environment, 327*, 81–92.

Qian, J. P., Zhang, L., Li, C. C., & Huang, D. (2013). Study on hair hg and Pb content distribution of traffic polices, Guilin. *Environmental Sciences, 34*, 2344–2349 in Chinese.

Samanta, G., Sharma, R., Roychowdhury, T., & Chakraborti, D. (2004). Arsenic and other elements in hair, nails, and skin-scales of arsenic victims in West Bengal, India. *Science of the Total Environment, 326*, 33–47.

Shi, L., Han, S. M., Wang, Z. W., Wang, D. Y., & Zhang, Y. L. (1999). Analysis on the content of nine kinds of trace elements in hair of preschool children. *Guangdong Trace Elements Science, 6*, 22–25 (in Chinese).

Skalnaya, M. G., Tinkov, A. A., Demidov, V. A., Serebryansky, E. P., & Nikonorov, A. A. (2014). Hair toxic element content in adult men and women in relation to body mass index. *Biological Trace Element Research, 161*, 13–19.

Tamburo, E., Varrica, D., & Dongarrà, G. (2016). Gender as a key factor in trace metal and metalloid content of human scalp hair. A multi-site study. *Science of the Total Environment, 573*, 996–1002.

Tang, X. D., Zhao, N., Gao, L. L., & Wang, M. (1999). Investigation and analysis of contents of Zn, Fe, Ca in preschool children's hair in Zhanjiang. *Studies of Trace Elements and Health, 16*, 48–50 in Chinese.

Tian, M. L., Zhong, X. M., Xia, D. S., Fu, F. Y., Lu, S. F., Li, L., & Song, B. (2016). Characteristics of heavy metal contents in human hairs of mine contaminated areas in Nandan County. *Environmental Sciences, 37*, 4867–4873 in Chinese.

Varrica, D., Dongarrà, G., Alaimo, M. G., Monna, F., Losno, R., Sanna, E., DeGiudici, G., & Tamburo, E. (2018). Lead isotopic fingerprint in human scalp hair: the case study of Iglesias mining district (Sardinia, Italy). *Science of the Total Environment, 613*, 456–461.

Wang, Y., Shu, C. L., Xia, Y. T., & Wang, C. S. (2012). Arsenic contents in urine and hair in a high arsenic village in Sihong County of Jiangsu Province. *Journal of Environmental Hygiene, 2*, 208–210 +217.

Wang, Y., Wang, D. Q., Qiu, S. J., & Qian, W. K. (2017a). Investigation on concentrations and spatial distribution characteristics of heavy metals in human hair of residents in Shanghai City. *Acta Scientiae Circumstantiae, 37*, 1139–1145 in Chinese.

Wang, Z. W., Yu, X. M., Geng, M. S., Wang, Z. L., Wang, Q. Q., & Zeng, X. F. (2017b). Accumulation of heavy metal in scalp hair of people exposed in Beijing sewage discharge channel irrigation area in Tianjin, China. *Environmental Science and Pollution Research, 24*, 13741–13748.

Wongsasuluk, P., Chotpantarat, S., Siriwong, W., & Robson, M. (2018). Using hair and fingernails in binary logistic regression for bio-monitoring of heavy metals/metalloid in groundwater in intensively agricultural areas, Thailand. *Environmental Research, 162*, 106–118.

Wu, M., Li, Z. Y., Chen, C., Chen, J., Zhang, M. T., Zhu, H. Q. (1993). Analysis of lead, copper and zinc content in children of workers exposed to low-dose lead. *Journal of Henan Medical University, 28*, 145–146 (in Chinese).

Xu, T. S., & Zhou, X. L. (1994). On relationship between hair and atmospheric pollution. *Journal of Shanghai Institute & Electric Power, 10*, 59–63 in Chinese.

Xu, X. J., Huo, X., Lin, K., He, Y. Z., Xu, L., & Wei, B. Y. (1999). Comparison of the contents of 9 elements in hair of children and adolescence. *Guangdong Trace Elements Science, 6*, 30–34 in Chinese.

Zheng, L. G., Tang, Q., Fan, J. M., Huang, X. Y., Jiang, C. L., & Cheng, H. (2015). Distribution and health risk assessment of mercury in urban street dust from coal energy dominant Huainan City, China. *Environmental Science and Pollution Research, 22*, 9316–9322.

Zhong, F. G., Shan, K. R., He, Y., Gu, Q. B., & Zhou, X. M. (1999). Comparative study on the hair arsenic contents from persons exposed arsenic in the area of coal type endemic arsenism. *China Public Health, 15*, 261–263 (in Chinese).

Zhou, S. S., Yuan, H. D., Ma, X. L., & Liu, Y. (2017). Hair chemical element contents and influence factors of reproductive-age women in the West Ujimqin Banner, Inner Mongolia. *Chemosphere, 166*, 528–539.

Zhu, Y., Wang, Y. Z., Meng, F. J., Li, L. F., Wu, S., Mei, X. H., Li, H., Zhang, G. X., & Wu, D. S. (2018). Distribution of metal and metalloid elements in human scalp hair in Taiyuan, China. *Ecotoxicology and Environmental Safety, 148*, 538–545.