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ORIGINAL PAPER

# Pollution levels and health risk assessment of potential toxic elements in road dust from different functional areas of Plateau city in SW China

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## Abstract

The potential toxic element (PTEs) contamination levels, sources, and exposure risk assessment in road dust (RD) from a typical plateau city in southwest China (Kunming) were conducted in this study. The RD was analyzed to determine the PTEs concentrations using ICP-MS. The enrichment factor (EF), geo-accumulation index ($I_{geo}$), and multivariate statistical analysis were employed to assess the pollution levels and source identification of PTEs, respectively. In addition, the health risk model was used to assess human health risks. The results showed that the concentrations of PTEs in each functional area could be arranged as follows: CA>TA>IA>RA. The $I_{geo}$ of Cu, Zn, and Cd were mostly 1–3, which illustrated moderately to heavily contaminate to these element contaminations in each functional (RA, TA, IA, and CA) based on the EF and PCA analysis that the main sources of heavy metals in RD from Kunming are anthropogenic source (61.8%) and natural source (13.4%). The health risk assessment indicates that chromium has a non-cancer risk for children in RA, whereas no cancer risk was found from the inhalation pathways in this study.


**Keywords** Pollution · Health risk · Toxic elements · Road dust · Plateau City · China

## Introduction

Numerous consistent studies suggest that the rapid population growth, rapid development of urbanization and industrialization lead to the urban environmental quality has deteriorated rapidly (Al-Dousari et al., 2017; Ghanavati et al. 2019; Qadeer et al. 2020; Jasrotia et al., 2021). Road dust (RD), the carrier of potential toxic elements (PTEs) and other toxic materials in urban environmental (Xiao et al. 2020), is a useful media to characterize quality of urban environmental (Wang et al. 2020a). RD resuspend into the atmosphere through the action of wind and disperse through different means of transportation, and then enter the human body via inhalation, ingestion, and dermal absorption, which will eventually cause harm to the health of people. It is estimated that more than 1.5 million people worldwide die prematurely every year from exposure to RD (Taiwo et al. 2020). Lead is a neurotoxic element that causes neurodegeneration, cognitive impairment (Mason et al. 2014), and premature delivery (Flora et al. 2011), in particular children, which can cause encephalopathy (Meng et al. 2016); Copper and zinc are essential nutrients, but beyond safety constraints, the former will have central nervous system stimulation, kidney disease, and liver disease, while the latter will have skin irritation, reproductive defects, anemia (Jahandari 2020); hexavalent chromium, cadmium, arsenic, and nickel are carcinogenic elements, while hexavalent chromium can cause damage to human DNA, associated with nasal and sinus cancers (Abreu et al. 2018; Rahman and Singh 2019); cadmium can induce cardiovascular disease, bone disease, and kidney disease, and even prostate and renal cancers (Larsson and

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Wolk 2016; Fagerberg et al. 2017; Rahman and Singh 2019); arsenic can lead to pigment precipitation, night blindness, abnormality of Mee's lines (Moradi et al. 2020); nickel can cause immune and nervous system diseases, and even lung cancer (Genchi et al. 2020; Son 2020). As a result of the above negative health effects of PTEs exposed to RD, the ecological and public health concerns have been raised for environmental pollution by PTEs (Doronzo et al. 2016; Doabi et al. 2018; Roy et al. 2019; Pragg and Mohammed 2020; Men et al. 2021).

During the past 10 years, the economy of Kunming city has grown rapidly with the total GDP value, urban population, and the number of cars in 2018 is 2.8, 1.3, and 3.3 times that of 2009 (KMBS, 2010, 2019). These factors are may lead to higher levels of PTEs in urban RD. Our work was conducted (1) to assess PTEs concentrations in RD in different functional areas and (2) to evaluate health risk of PTE in RD from Kunming city. In view of the limited information on PTEs pollution levels and related ecological and health risks caused by RD in Kunming, this research work will help to improve the pollution related to traffic management and improve the environmental quality of Kunming city.

## Methods and materials

Kunming (102° 10′-103° 40′ E, 24° 23′-26° 22′ N), located in the southwest of China, is a plateau city and the fourth largest city in western China, with an elevation of 1891 m, the mean annual temperature of 15 °C, and the city covers an area of $2.1013\times10^4$ $km^2$. A total of 45 samples (3 sub-samples for each sampling site) of RD were collected during November 2020 from four different functional areas (Fig. 1): 15 from residential area (RA), 12 from traffic area (TA), 9 from commercial area (CA), and 9 from industrial area (IA). At each sampling site, a disposable nylon brush was used to lightly brush about 50.00g of RD in a 1-square-meter area of the ground and the collected samples were stored in sealable and numbered labels polyethylene bags, which were brought back to the laboratory. All samples were naturally air-dried in the laboratory, and then, RD with a diameter ($d$) of >75 μm was removed from the samples using a nylon sieve with a 200 mesh.

Detailed sample weighing and digestion methods are described in Wang et al. (2020b) report. Briefly, the samples were digested by acid digestion method ($HNO_3$-HF), and the contents of Cu, Mn, Pb, Zn, Cd, Ni, Cr, were determined by ICP-MS (DRC-e, USA. PerkinElmer). We use standard material (GSS-4) for quality control during digestion and instrument analysis. One parallel sample and blank sample (including sample and reagent blanks) are added to every 10 samples. The measured values of elements in the reference material were all within the ranges of standard values, with a relative standard deviation (RSD) of each element is less than 5%.

In order to evaluate the sources, pollution levels and harm to human health of PTEs in RD from different functional areas, enrichment factor (EF), geoaccumulation index ($I_{geo}$), principal component analysis (PCA), and health risk assessment method were introduced in our research. Their calculation formulas and related parameter can be found in the supplementary material (Table S1, Table S2, Table S3, and Table S4).

## Results and discussion

The total levels of PTEs (Cr, Cu, Zn, Pb, Ni, and Cd) in the RD samples summarized in the Fig. 2. Illustrated by Fig. 2 and Table 1, the mean concentrations of PTEs in the study area are arranged like this: Zn>Cu>Cr>Pb>Ni>Cd. Compared with other cities, Kunming has higher concentrations of PTEs in RD than other large cities in China (e.g., Chengdu and Beijing) (Li et al. 2017). In our study, the Zn (624.23 mg/kg) was found to be the most abundant element in RD, which was 6.96 times of the soil background value. The high concentrations of zinc may come from galvanized road equipment (e.g., lamp posts, road signs, and crash barriers), which is released from corrosion due to various conditions (Yuen et al. 2012; Huang et al. 2014). The average concentrations of Cr, Cu, Pb, and Ni were 2.21, 3.85, 2.92, and 0.94 times of the corresponding soil background values, respectively. Furthermore, although the mean concentration of Cd (3.35 mg/kg) was the lowest among all elements, it was 15.37 times the soil background value.

The concentration of PTEs in RD from different functional areas of Kunming was depicted in Table 1. Except for Ni elements in the RA and TA, the other element concentration exceeds the local soil background values in RA, TA, IA, and the CA, indicating that heavy metals in urban RD may come from natural and anthropogenic emissions. According to the total concentration of elements in each functional area, they can be arranged like this: CA>TA>IA>RA; this result is similar to that in Chengdu, China (Li et al. 2017), Zahedan, Iran (Kamani et al. 2015), and Villavicencio, Colombia (Manuel Trujillo-Gonzalez et al. 2016). In addition, different land use types will cause different changes in the concentration of PTEs. For example, zinc (779.03mg/kg) and lead (127.72mg/kg) are the highest in CA, copper (223.64mg/kg) and cadmium (5.85mg/kg) are the highest in TA, nickel (46.99mg/kg) is the highest in IA, and chromium (155.32mg/kg) is the highest in RA. Therefore, the unique artificial activities of each functional area can discharge different kinds of PTEs and then deposit on the road surface, which leads to the difference of metal level between different functional areas (Manuel Trujillo-Gonzalez et al. 2016).

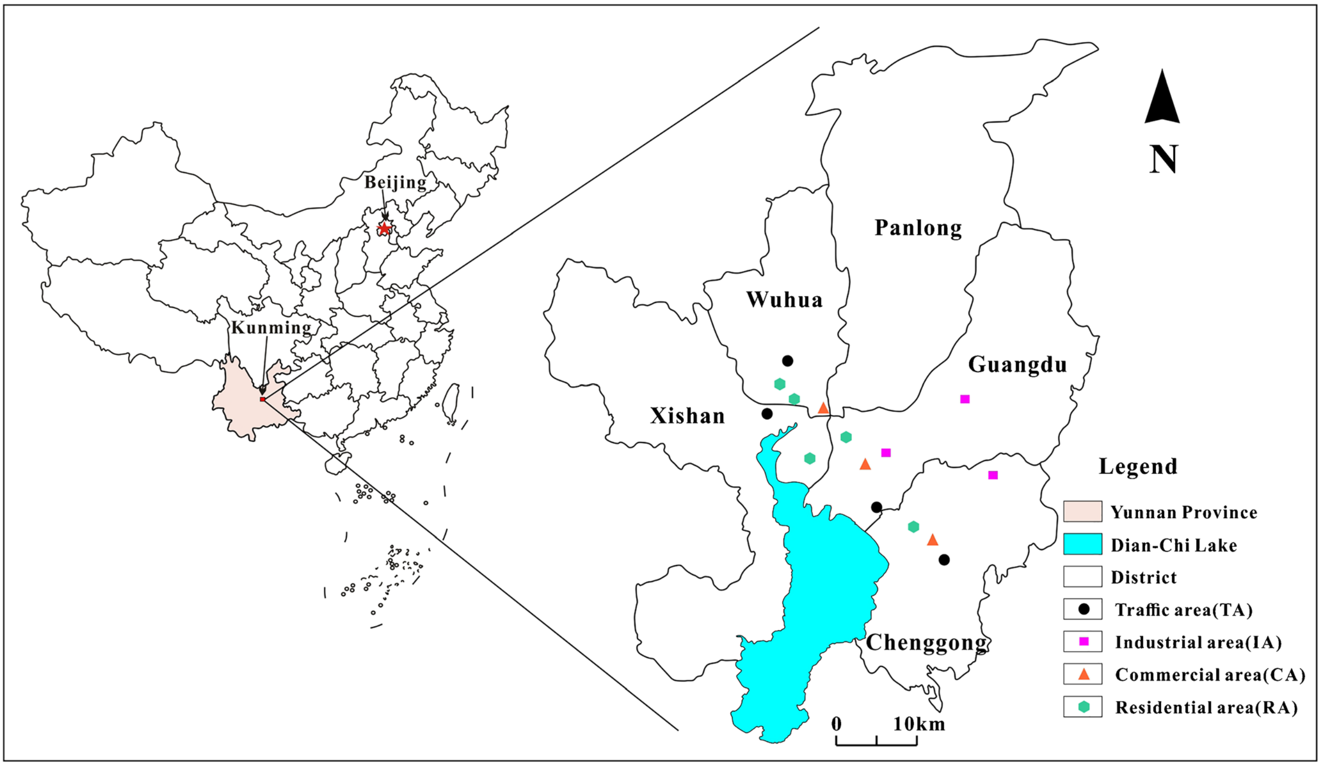



**Fig. 1** Map of study area, sampling points

Illustrated by Table 2, the mean EF were 1.81 for Cr, 3.17 for Cu, 5.54 for Zn, 2.37 for Pb, 0.75 for Ni, and 12.07 for Cd, and they could be classified as follows: Cd>Zn>Cu>Pb>Cr>Ni. The EF values of Cd in RA, TA, IA, and CA are in the range of 5–20, which is significant enrichment. The EF values of Cu and Pb in RA, TA, IA, and CA are in the range of 2–5, which is moderate enrichment. EF values for Ni in RA, TA, IA, and CA were lower than 1, illustrating that anthropogenic factors are not remarkable. The mean $I_{geo}$ were 0.46 for

**Fig. 2.** Total concentration of PTEs in RD from Kunming City

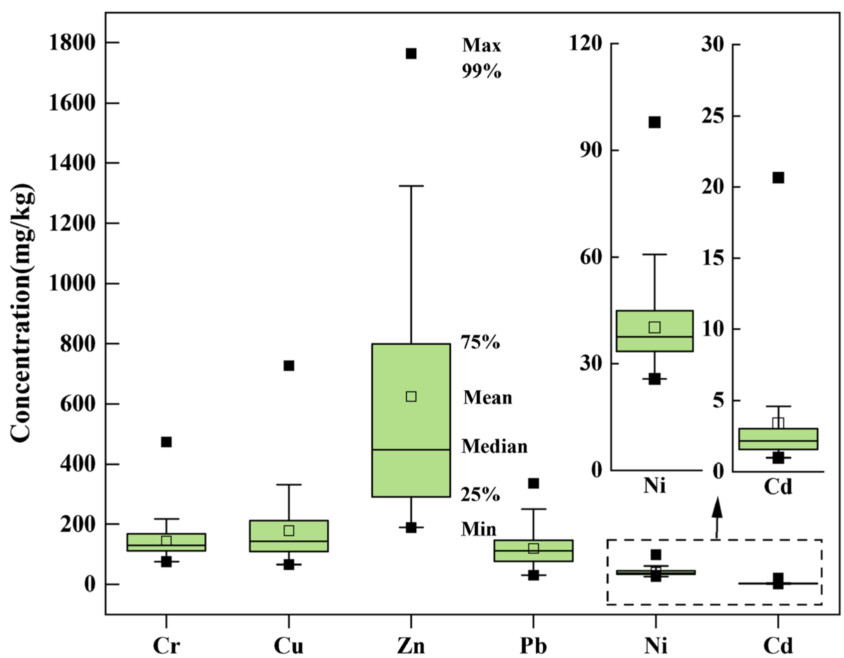


**Table 1** Heavy metal concentrations in RD with different functional areas of Kunming City ($n$=45, mg/kg)

| Element | RA($n$=15) | | | | TA($n$=12) | | | | IA($n$=9) | | | | CA($n$=9) | | | | BV [a] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Max | Min | *SD* | Mean | Max | Min | *SD* | Mean | Max | Min | *SD* | Mean | Max | Min | *SD* | |
| Cr | 155.32 | 472.56 | 85.88 | 94.75 | 122.88 | 168.52 | 75.07 | 29.98 | 150.16 | 271.05 | 79.25 | 57.01 | 148.62 | 217.08 | 78.67 | 46.93 | 65.2 |
| Cu | 130.51 | 243.89 | 65.12 | 50.50 | 223.64 | 577.63 | 95.33 | 135.99 | 217.60 | 726.93 | 78.04 | 203.20 | 158.57 | 298.37 | 80.46 | 70.11 | 46.3 |
| Zn | 509.05 | 1129.07 | 188.70 | 305.63 | 742.06 | 1763.11 | 276.71 | 452.33 | 504.26 | 1641.74 | 215.93 | 444.37 | 779.03 | 1749.03 | 232.83 | 453.80 | 89.7 |
| Pb | 116.97 | 335.79 | 47.84 | 76.78 | 117.67 | 174.62 | 39.75 | 39.75 | 113.99 | 243.28 | 30.21 | 72.53 | 127.72 | 250.45 | 54.65 | 54.65 | 40.6 |
| Ni | 33.73 | 52.73 | 25.68 | 7.40 | 40.28 | 64.54 | 28.57 | 10.21 | 46.99 | 97.86 | 30.21 | 19.96 | 43.59 | 60.71 | 33.72 | 9.21 | 42.5 |
| Cd | 2.64 | 8.94 | 0.97 | 2.05 | 5.85 | 20.65 | 1.45 | 6.06 | 1.89 | 3.55 | 1.03 | 0.72 | 2.66 | 5.21 | 1.23 | 1.33 | 0.218 |

[a] Background values of the elements in Yunnan Province, CNEMC (1990). *SD* standard deviation

**Table 2** Enrichment factor (EF), geo-accumulation index ($I_{geo}$) of Cr, Cu, Zn, Pb, Ni, Cd in RD

| Sites | EF | | | | | | $I_{geo}$ | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cr | Cu | Zn | Pb | Ni | Cd | Cr | Cu | Zn | Pb | Ni | Cd |
| RA (*n*=15) | 2.03 | 2.32 | 4.42 | 2.42 | 0.64 | 9.48 | 0.52 | 0.82 | 1.70 | 0.73 | −0.95 | 2.74 |
| TA (*n*=12) | 1.38 | 3.89 | 6.66 | 2.25 | 0.70 | 20.82 | 0.29 | 1.49 | 2.25 | 0.86 | −0.70 | 3.54 |
| IA (*n*=9) | 1.81 | 3.74 | 4.16 | 2.16 | 0.86 | 6.57 | 0.53 | 1.28 | 1.60 | 0.61 | −0.52 | 2.45 |
| CA (*n*=9) | 2.00 | 3.06 | 7.31 | 2.65 | 0.90 | 10.20 | 0.54 | 1.07 | 2.29 | 0.96 | −0.58 | 2.87 |
| Mean (*n*=45) | 1.81 | 3.17 | 5.54 | 2.37 | 0.75 | 12.07 | 0.46 | 1.14 | 1.94 | 0.79 | −0.72 | 2.92 |

Cr, 1.14 for Cu, 1.94 for Zn, 0.79 for Pb, −0.72 for Ni, and 2.92 for Cd, and they could be classified as follows: Cd>Zn>Cu>Pb>Cr>Ni. The $I_{geo}$ data for Ni indicated was unpolluted level while uncontaminated to moderate levels for Cr and Pb; copper and Zn were moderately contaminated; The $I_{geo}$ data for Cd is greater than 2 but less than 3, illustrating that there was moderately to heavily contaminated. In addition, the EF and $I_{geo}$ of Cd in the RD from TA were higher than in other functional areas. Complicated anthropogenic sources give rise to the high Cd concentration in the TA area with a higher vehicle density. In fact, the number of motor vehicles in Kunming has been increasing continuously in recent years, reaching 2.5 million by 2019 (KMBS, 2020). Therefore, tires and car batteries are potential sources of Cd pollution.

In our study, principal component analysis (PCA) was used to determine the main sources and contributions of PTEs in RD from Kunming City. Table S5 shows that the first three factors (PC1, PC2, and PC3 were 39.1%, 22.7%, and 13.4%, respectively) explain 75.2% of the total variable. PC1 is vital and accounts for about 39.1% of the total variance. This factor may be related to vehicles, for example, Zn and Cd are used in the manufacture of car tires, zinc borate is used as an additive in polymers needed to make car glass, and lead, cadmium, and zinc are also known to be trace elements in traffic exhaust (Heidari et al. 2021; Vlasov et al. 2021). In addition, correlation analysis also showed that Pb-Zn, Cd-Zn, Cd-Cu, and Zn-Cu had strong positive correlations, which were 0.422, 0.517, 0.364, and 0.379, respectively (Table S6). PC2 was dominated mainly by Cr with a loading value of 0.7 and accounts for 22.7% of the entire variance. Generally, the Cr in urban dust is chiefly derived from traffic emissions, industrial activities, consumption residuals, and thermal power plants (Han and Lu 2017; Pan et al. 2017; Yu et al. 2021). In our research, the average concentration of Cr was 2.21 times of the background value of the soil. Combined with the geographical location of Kunming city and the power plant, it was concluded that the Cr in the RD studied was mainly dominated by emissions from coal-fired power plants. Contributions of PC3 to the total variance comprise 13.4%. This factor mainly comes from natural sources (e.g., local soil).

Taking into consideration the adverse influences of PTEs on human health, the values of $HQ_{\text{ing}}$, $HQ_{\text{inh}}$, $HQ_{\text{derm}}$, and $HI$ were calculated. For children, the HI value of Cr in RA is 1.01 (exceeding safety value of 1), illustrating that children have a non-carcinogenic risk (Fig. 3). For adults, the *HI* value of PTEs in RA, TA, IA, and CA is exceeded safe value of 1, illustrating that adults have no non-carcinogenic risk (Fig. 4). In addition, as shown in Fig. 3 and Fig. 4, the level of ingestion to HI was the highest in all four areas, among the exposure pathways. Therefore, ingestion is the main exposure pathway of PTEs in RD from Kunming. In our research, we use Cr, Ni, and Cd to assess carcinogenic risk. As shown in Fig. 5, Cr, Ni, and Cd were lower than the acceptable threshold value 1E-6 in all functional areas, illustrating that Ni, Cd, and Cr have no carcinogenic risk to RD exposure.

## Conclusions

The PET levels in the RD from different functional areas of Kunming city in SW China were assessed. Furthermore, the human health risks caused by PTEs were investigated. The average level of Cr, Cu, Zn, Cd, Pb, and Ni was all higher than the corresponding soil background values in Yunnan Province. According to the total concentration of elements in each functional area, they can be arranged as like this: CA>TA>IA>RA. EF and $I_{geo}$ studies show that the heavy metals have the same order as follows: Cd>Zn>Cu>Pb>Cr>Ni. Zinc, copper, and cadmium are the main pollutant elements in CA, TA, IA, and RA, and their $I_{geo}$ values range from the level of moderately to heavily contaminated. PCA showed that the main sources of RD in Kunming city were traffic exhaust, tire

Fig. 3 HQ and HI of PTEs for children in different functional areas

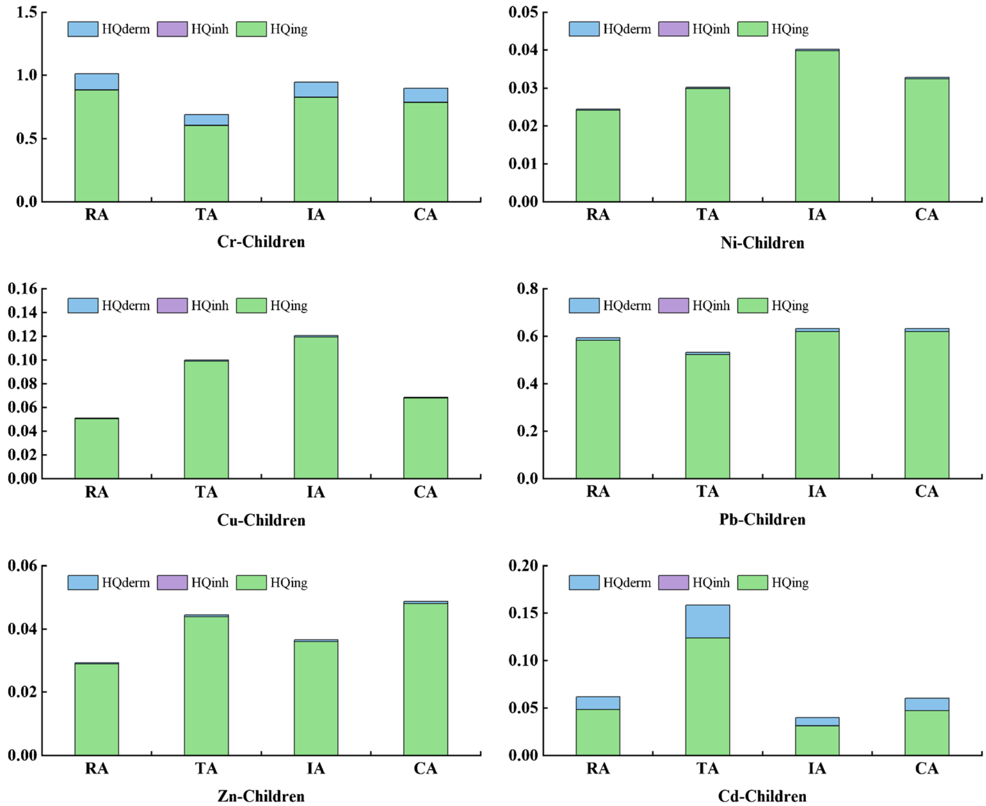
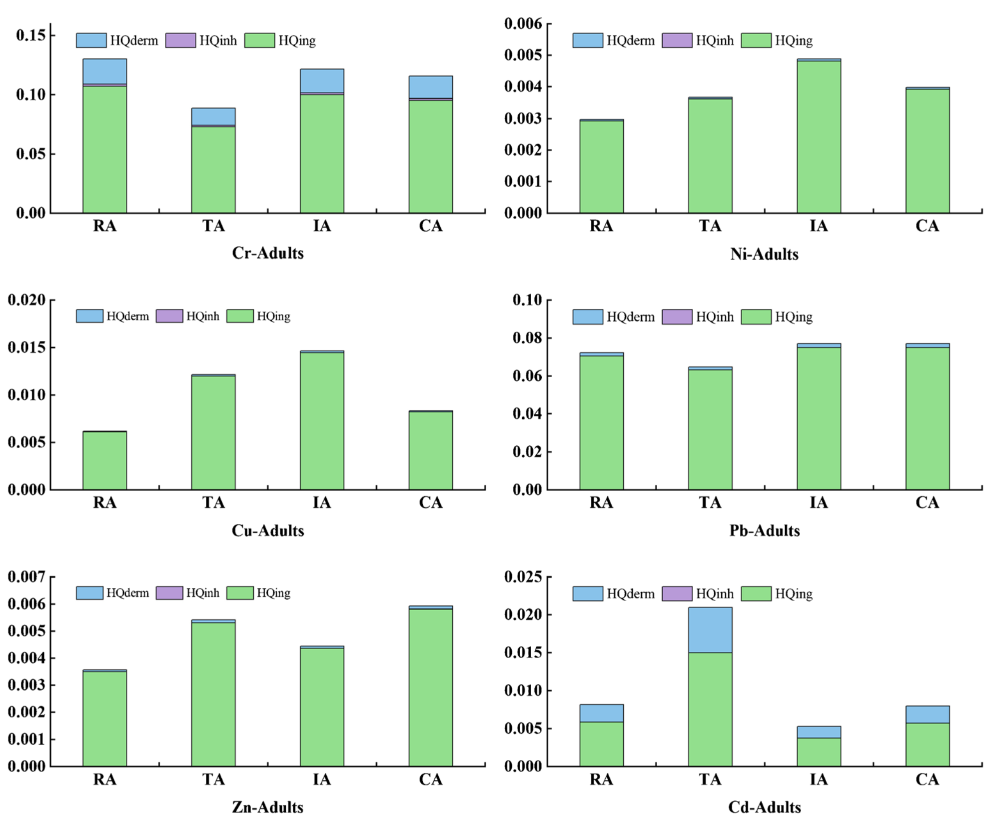



Fig. 4 HQ and HI of PTEs for adults in different functional areas



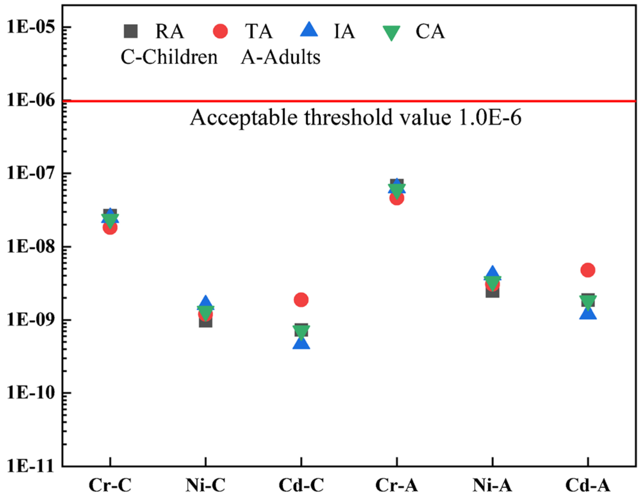



**Fig. 5** Cancer risk of Cr, Ni, and Cd in different functional areas

wear, coal burning, and natural sources (e.g., local soil). The health risk assessment model showed that the HI children-RA value of Cr is higher than safety level, illustrating that children have non-cancer risk. The results also determine the carcinogenic risk thresholds for Cr, Ni, and Cd, which were all lower than 1E-6, and have no carcinogenic risk.

**Supplementary Information** The online version contains supplementary material available at https://doi.org/10.1007/s12517-021-08346-y.

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