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Ecological and health risk assessment of trace elements in surface soil in an arid region of Xin Jiang, China

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Abstract:

Purpose: Trace element pollution in soil has become an increasingly common issue and potentially harms the environment and human health. In this study, the contamination levels and ecological and health risk indices of trace elements in surface soils in Bai Cheng, Xin Jiang were investigated in order to examine if the land usage changed from pasture to agriculture has influenced the behaviours of these trace elements.

Material and methods: In this study, descriptive analysis, normality test, the Tukey-HSD method, and non-parametric methods were used to investigate the characteristics of trace elements. The geo-accumulation pollution and ecological risk indices were used to analyse the degree of contamination by trace elements. Correlation and principle analyses were used to identify the sources of trace elements and a health risk assessment was used to analyse human exposure to trace elements of the soil.

Results and discussion: Cadmium was the main pollutant in the 0–5cm soil layer in both agricultural and pastoral areas. Thus, it contributed most to the Geo-Accumulation Index (I*geo*) and the comprehensive potential ecological risk index (RI) of the surface soils. The levels of RI for the topsoil layer of agricultural areas fell into moderate to high (II-III) ecological risk categories, and those of pastoral areas belonged to low to moderate risk categories (I-II). Both values of I*geo* and RI of the surface soils in agricultural areas were higher than in pastoral areas. The carcinogenic risk of Cr through hand-to-mouth intake and the total risk of trace elements in soils for humans were higher than the safety reference level. Chromium was the greatest contributor to total carcinogenic risk.

Conclusions: Trace element concentration levels in surface soils in pastoral areas were relevant to geochemical characteristics and atmospheric deposition; whereas trace element concentration levels in surface soils in agricultural areas were derived not only from geochemical characteristics but also from human activities. The change in land use from pasture to agriculture increased the trace element concentration level in surface soils. There were both ecological risks and human health implications for residents exposed to such contaminants of soils in the studied region.

Keywords: agricultural and pastoral areas, ecological and health risk, soil, trace element, Xin Jiang, China

1 Introduction

The distribution of trace elements in soil not only affects the quality of soil but also directly affects the survival of animals and crops, and human health (Shen et al. 2017). If the supply is insufficient or excessive, it may cause physiological dysfunction of animals and plants, and induce various special physiological diseases in humans (Zeng et al. 2015). Rapid development of industry and agriculture is an important factor affecting the health of regional ecosystems, due to the increase in trace element concentrations in surface soils (Liu et al. 2018). Moreover, because of the long period, wide range and biodegradability of trace element pollution in the soil, trace elements easily accumulate in surface soils, and possibly build up in the food chain, thus endangering human health (Abbas et al. 2017). In addition, they may also enter the human body through direct contact, dust inhalation, and hand-to-mouth intake (Doabi et al. 2018).

According to the National Soil Pollution Investigation Bulletin, issued by the Ministry of Land and Resources of China in 2014, the proportion of soil sites with above-standard levels of trace elements accounts for 16.1% of the total land area of China (Chen et al. 2019). Among the pollutants noted, cadmium (Cd), mercury (Hg), arsenic (As), lead (Pb), chromium (Cr), copper (Cu), nickel (Ni), and zinc (Zn) are all above the average levels (Xie et al. 2019). Thus, trace element pollution and ecological risk assessment are of particular interest to geographic, soil, and environmental sciences, as well as an important indicator of regional environmental quality assessment in China (Zhang et al. 2019). A number of studies have examined the distribution, sources, and pollution assessment of trace elements in soils of different regions (Zhang et al. 2016; Zheng et al. 2013; Zhu et al. 2017), and have achieved important research results. So far, these related researches have concentrated mainly on the eastern and southern parts of China with regions showing a high level of economic development. However, there is a lack of research on environmental hazards caused by economic development in the oasis basins and mountainous areas of the arid regions of Northwest China.

In geography, an oasis is a fertile area (often having a date palm grove) in a desert or semi-desert environment (Ramdani, et al. 2018). In addition, an oasis is a heterogeneous ecological landscape with obvious microclimate effects on an arid area. As a result of the combined effect of drought conditions and human activities, specifically the change in land use from pastoral to crop cultivation, problems of trace element contamination with soil environmental safety are arising in oases of different regions. Thus, ecological and health risk assessment of trace elements is the focus of attention. As oases in the arid area of Xin Jiang are the centre of resources and economic activity, they attract large numbers of people, up to 95% of the population, to live in an area that relates to approximately 5% of the territory. With the growing development of agriculture and industry in Xin Jiang, not only the economy is developing rapidly, also pollution relating to trace elements in oasis soils is becoming more severe than ever (Mamut et al. 2018). The ecosystem structure in the arid regions of western China is fragile and weak (Turdi and Yang 2016). One of its characteristics is its limited ability to absorb and recover from external impacts. Therefore, trace element pollution in the soil of Western China can easily cause irreversible damage to the local ecosystem.

However, t no study has investigated whether the change in land usage from pasture to agriculture has influenced the concentration levels of trace elements and their ecological pollution index and exposure level. Thus, in this study, a traditional farming (agricultural) and animal husbandry (pastoral) area, Bai Cheng in southern Xin Jiang, was selected as the research region. The distribution characteristics and sources of trace elements in different traditional farming and animal husbandry areas were analysed by descriptive statistical methods. The I*geo*, Potential Hazard Assessment Index and US EPA Health Risk Assessment Model were used to assess the ecological risks and potential health risks of trace element pollution in soils, with particular focus on surface soils, in order to determine the influence of the increasing intensity of modern agriculture on oases in Xin Jiang. The results of this study will provide a scientific basis for the development and utilisation of oasis farmland and the management of soil environmental risks.

2 Materials and methods

2.1 Study area

This study focused on trace element contaminations of surface soils in which wheat is cultivated and natural soils of pastoral lands in the Bai Cheng Region, southwest of the Xin Jiang Uyghur Autonomous Region. It is located between 80°37′39″–83°02′25″ E and 41°24′08″–42°38′52″ N (Cheng 2009; Pan 2013). The Heyingshan (KYR), Laohutai (KRW), Dawanqi (DW), and Yaturi (YTR) are typical flooding irrigation agricultural areas, while Yang Chang (YC) and Bulong (B) are pastoral areas. DW and YTR and B are located on a plain, whereas KYR, KRW and YC are high altitude areas. The sampling points are shown in Fig. 1.

Traditional and typical agriculture and pastoralism in the area is a kind of subsistence agriculture or pasture activities with limited agricultural or pastoral products. Family members participate in a production labour and perform part of the family’s work. Agricultural and pastoral production is mostly based on accumulated experience and the production method is relatively stable. The traditional agricultural and pastoral production level is low, surplus is small, and accumulation is slow. The output is greatly affected by naturally environmental conditions.

2.2 Sample collection and preparation

A total of 160 soil samples at a depth of 0–5 cm in agricultural land and a total of 80 soil samples at the same depth in pastoral area land were collected with a plastic coated stainless-steel spatula.

The collected soil samples were placed in polyethylene bags, labelled and then air-dried until they were fully dried (Abbas et al. 2017; Saha et al. 2016). The dried soil samples were homogenised, sieved (< 0.6 mm) and milled in compliance with ISO-11464, and finally stored in sealed polyethylene bags before chemical analysis (Amorosi et al. 2014).

2.3 Instrumental analysis and quality control

2.3.1 Analysis of elements

Each dried soil sample was weighed accurately to 0.05 g, placed in a microwave Teflon vessel, and digested with a solution of 5:1 concentrated HNO_3:70% HClO4 (V/V) at temperatures between 90 and150°C on an electric heating plate (Chen et al. 2016). The liquid prepared by the digestion process was diluted to 25ml with deionised water, shaken evenly and then stored for 24 hours before analysis. The concentrations of Zn, Mg, Mn, Pb, Ni, Cd, Co, Fe, Cu and Cr were determined by using the inductively coupled plasma mass spectrometry (ICP-MS) and inductively coupled plasma-optical emission spectrometry (ICP-OES). The concentrations of As and Se were analysed using Atomic Fluorescence Spectrometry (AFS).

2.3.2 Quality control

The accuracy of the analyses was checked against samples of soils with certified materials (GBW10011, China National Centre for Standard Materials) of selected trace elements in this study. In each analytical batch, 15% of the samples were analysed twice in order to ensure the precision and accuracy of the analysis. Internal reference standard materials and reagent blanks were also used to ensure high precision and to check if there were any inaccuracies during the laboratory analysis (Liu et al. 2015).

2.4 Statistical analysis

In this study, descriptive analysis, normality test, the Tukey-HSD method, and non-parametric methods were used to analyze trace element concentration levels. The geo-accumulation pollution index and ecological risk index were used to analyse the degree of contamination by trace elements; the non-parametric correlation analysis and principal component analysis methods were used to identify the source of trace elements; and the health risk assessment method was used to analyse the exposure and risk to trace elements in the soil.

Twice as many samples were taken from farmed areas compared to pastoral areas that are the reason why non-parametric tests were used, including Tukey-HSD to compare the concentration level of the trace elements between the agriculture and pastoral areas. In addition, PCA (principal components analysis) is a legitimate statistical technique used with the given data characteristics.

2.5 Metal contamination assessment

2.5.1 Geo-Accumulation Index

The I*geo* was used to estimate the pollution level of trace elements in soils (Mamut et al. 2018).

The I*geo* is defined in Eq. (1) as follows:

$$Igeo=\log 2\ [Ci/\ (1.5*Bi)\ (1)$$

where Ci is the measured concentration of a trace element, Bi is the geochemical background value of a trace element in the soil of Xin Jiang, and 1.5 is the coefficient of variation (CV) resulting from rock formation. Using I*geo*, pollution levels can be classified as no pollution (I*geo*≤0), slight pollution (0<I*geo*<1), partially moderate pollution (1<I*geo*<2), moderate pollution (2<I*geo*<3), partially serious pollution (3<I*geo*<4), serious pollution (4<Igeo<5), or severe pollution (I*geo*>5).

2.5.2 Potential ecological risk index

The ecological risk level of trace elements was analysed using the Ecological risk index (ERI) (Zhang et al. 2018). The ERI can be calculated using Eq. (2):

$$\mathrm{ERI}=\sum\ Ei$$

$$=\sum_{I}^{M} T\,i \times \frac{Ci}{Cb} \qquad (2)$$

Where Ti is the toxic response factor of an element; the Ti for As, Cd, Cr, Cu, Ni, Pb, and Zn is 10, 30, 2, 5, 5, 5, and 1, respectively (Zhang, et al. 2017). E is the contamination factor of element i; Ci is the measured concentration of elements, and Cb is the Soil Environmental Quality Standard of China (GB15618-1995) (pH>7.5) (Table S1). The risk level of E of every single element can be classified as low risk (E<40), moderate risk (40≤E< 80), considerable risk (80≤E < 160), high risk (160≤E< 320), and extremely high risk (E≥320). The ecological RI level can be classified as low risk (RI < 150), moderate risk (150≤RI< 300), considerable risk (300≤RI<600), high risk (600≤RI<1200), or very high risk (RI≥1200).

2.5.3 Potential human health risk assessment

The potential health risks caused by three main routes of exposure (ingestion, inhalation, and dermal) to trace element contaminants in soils were assessed based on the health risks models of the U. S. EPA (Saha et al. 2016).

In this study, exposure assessment of local residents was carried out by measuring the chronic daily intake (ADD) of trace elements in soils through multiple pathways (inhalation, ingestion and dermal contact). The corresponding ADD (mg kg^{-1} day^{-1}) received through three preferential pathways were separately determined and expressed using Eqs. (3)–(5):

$$\mathrm{CDI}m_{\mathrm{ing}}\frac{Cm*IngR*EF*ED}{BW*AT}*10-6 \qquad (3)$$

$$\mathrm{CDI}m_{\mathrm{inh}}=\frac{Cm*InhR*EF*ED}{PEF*BW*AT}*10-6 \qquad (4)$$

$$\mathrm{CDI}m_{\mathrm{der}}=\frac{Cm*SA*SL*ABS*EF*ED}{BW*AT} \qquad (5)$$

where m is the metal of interest, $\mathrm{CDI}m_{\mathrm{ing}}$, $\mathrm{CDI}m_{\mathrm{inh}}$, and $\mathrm{CDI}m_{\mathrm{der}}$ are the average daily doses of metal (m) via ingestion, inhalation, and dermal contact, respectively, Cm is the concentration of metal (m) in soil samples (mg/kg), $IngR$ and $InhR$ are the ingestion and inhalation rates, respectively, EF is the exposure frequency and ED is the exposure duration, BW is the body weight, AT is the average time, PEF is the particle emission factor, SA is the exposed skin area, SL is the skin adherence factor, ABS is the dermal absorption factor. The above exposure variables were based on the results of the questionnaires, the relevant research (Zheng et al. 2013), the standards of the U. S. Environmental Protection Agency (EPA 2004), and the report by the Environmental Ministry of China (2010) (Table S2).

Non-carcinogenic hazard quotient (HQ)

The non-cancer risks of exposure to elements in the soil were calculated as follows (Eqs. (6)-(7):

$$\text{HQ} = \frac{CDI}{RFD} \qquad (6)$$

$$\text{HI} = \sum HQ\, pm \qquad (7)$$

As stated earlier, the chronic daily intake (CDI) of trace elements in soils through multiple pathways (inhalation, ingestion and dermal contact) were calculated using Eqs. (3)-(5) separately. The hazard quotient (HQ *p, m*) represents the non-carcinogenic risk for each metal through the exposure pathway. The reference doses (*RFD*) were taken from the U. S. Department of Energy's RAIS compilation (U. S. Department of Energy 2004) (Table S3). The hazard index (HI) represents the total non-carcinogenic risk for each element through the three exposure pathways.

Carcinogenic risk

The carcinogenic risk (CR) is the incremental probability of an individual developing cancer over a lifetime due to carcinogenic exposure (Mora et al. 2009). The carcinogenic risk is evaluated by Eq. (8):

$$CR = CDI \times CSF \qquad (8)$$

The estimated *CR* is the probability of an individual developing in any type of cancer from lifetime exposure to carcinogenic hazards. *CDI* is the chronic daily intake and *CSF* is the cancer slope factor (expressed in in mg kg^{-1} day^{-1}) (Table S3).

To evaluate the total potential cancer risks (TCR) from all of these elements together in three pathways for the soil, these parameters were calculated using Eq. (9).

$$TCR = \sum^{n} \text{CR} \qquad (9)$$

CR is the individual carcinogenic risk of every element; *n* is an element that causes cancer risk.

3 Results and discussion

3.1 Trace element concentration of surface soils in agricultural and pastoral areas

A statistical summary of the concentrations of elements at a depth of 0–5cm surface soils of the agricultural and pastoral areas in Bai Cheng County is given in Table S4 and Fig. 2. These results were compared with the background levels of soils in Xin Jiang and the Soil Environmental Quality Standard of China (GB15618-1995) (pH > 7.5).

It can be seen from Table S4 and Fig. 2 that the average levels of some trace elements exceeded the background levels of soils in Xin Jiang. The minimum and average levels of Cd in both agricultural and pastoral areas exceeded the limit values of Soil Environmental Quality Standard of China (GB15618-1995). Therefore, Cd is the main pollutant in surface soils in both agricultural and pastoral areas.is. The soils in these studied areas are weakly alkaline. It is reported that most of the metals in the soil are in the form of insoluble compounds, which usually do not migrate readily (Li 2017). With the passage of time, the accumulation of metals in the surface soil becomes more and more obvious. This showed that the soil in the studied area had been affected by the pollution of exogenous metals for a long time, thus the elements exceeded the background levels due to their enrichment in soils.

Figure 2 shows that there was a significant difference in the trace element concentration levels between the agricultural areas and the pastoral areas. The enrichment and accumulation of trace elements in soils are influenced by the types and forms of trace elements; parent material of the soil and characteristics of the geochemical background; physicochemical properties of the soil; type of land use; and level of N, P and K in the soil (Tudi et al. 2013; Zhang et al. 2014). In addition, land use changes from pastoral areas to crop cultivated agricultural areas where new modern agricultural techniques and pesticide inputs are applied may increase the trace element concentration levels. Thus, there were significant differences in trace element concentration levels between the agriculture areas and the pastoral areas.

3.2 Assessment of trace element contamination in soils

3.2.1 Geo-Accumulation Index (I*geo*)

The I*geo* of soils from farmland and pastoral areas in Bai Cheng County were analysed, and the results are shown in Table 1. In the agricultural areas, the average I*geo* indices of Cu, Cr, Pb, and As were less than 0, indicating a pollution-free condition; while the maximum accumulative indices of Cu, Cr, Pb and As were between 0 and 1, indicating light-medium pollution (Level 2). The average and maximum accumulative indices of Mn and Co were less than 0, indicating a pollution-free condition. The average and maximum accumulative indices of Zn were between 0 and 1 and the maximum indices were between 1 and 2, which indicated light-to-moderate pollution (between Level 2 and Level 3). The average and maximum accumulative indices of Ni were between 0 and 1, indicating light pollution (Level 2). The average value of Cd was between 1 and 2, indicating moderate pollution (Level 3). The maximum accumulative index of the Cd was 3.4, belonging to the high pollution category (Level 4).

In the pastoral areas, the average and maximum accumulative indices of Cu, Co, Mn and Cu were less than 0, indicating a pollution-free condition; the average and maximum accumulative indices of Ni, Pb and As were less than 0, but their maximum values were between 0 and 1, indicating light-moderate pollution (Level 2); the average accumulative indices of Cd were between 1 and 2, and the maximum value was between 2 and 3, indicating medium to severe pollution (Level 3–4). These results showed that there was less pollution by trace elements in pastoral areas than in agricultural areas.

3.2.2 Potential ecological risk assessment

The individual potential ecological risk index (E) and the integrated potential ecological ERI can represent the sensitivity of various ecosystems to toxic substances and identify the potential ecological risks caused by trace elements (Zhang et al. 2017). The E and RI of soils from the top layer (0–5cm) of the agricultural and pastoral areas in Bai Cheng County were calculated according to Eq. (4), and the results are shown in Table 2.

Generally, the biological toxicity of Cd is the greatest among these elements (Wiggenhauser et al. 2016; Yousaf et al. 2016). Consequently, its risk is dominant and classified as the highest in this study, while the biological toxicity of Ni, Cu, Zn, Cr, Co, Pb, and As is respectively lower with a correspondingly lower risk. According to the evaluation of potential and integrated ecological risks, pollution by trace elements in the pastoral areas was less than that in the agricultural areas. The average and maximum RI values for the pastoral areas were 151.6 and 331.2, revealing that these areas were in low to moderate (i-ii) risk. The average and maximum ERI values for the agricultural areas were 188.3 and 555.2, respectively. Thus, agricultural land had moderate to high risk (ii-iii). The pollution levels in agricultural soils were higher than in pastoral soils, suggesting that the high degree of pollution of agricultural soils could be attributed to unreasonable agricultural activities, such as the overuse of pesticides and chemical fertilizers (Chen et al. 2016).

The Hakanson evaluation system considers the toxicity of a trace element, while the I*geo* evaluation focuses more on evaluating the degree of trace element pollution. For this reason, it is necessary to take this into consideration when using multiple systems to evaluate the regional pollution situation in order to reflect it comprehensively and objectively. The combination of these two evaluation systems can identify trace element pollution with more precision and the results are highly consistent with those of previous work (Mamut et al. 2018).

The results showed that the Cd concentration level in agricultural and pastoral soils in Bai Cheng County were significantly higher than the Xin Jiang soil background level and the level settled by the China National Soil Standard. In addition, the results of the pollution assessment indicated that Cd was the dominant pollutant in the soils of both agricultural and pastoral areas. Cadmium contributed significantly to the Geo-Accumulation Index and the comprehensive potential ecological index (RI) in the studied region. Therefore, this was the main reason for the moderate to high potential ecological risk situation in this region. This result was consistent with previous studies, which indicated that the proportion of Cd pollutant accounted for 56% of the total soil pollution in China (Mamut et al. 2018; Mamattursun et al. 2017).

The following reasons were taken into account for the considerable Cd pollution and ecological and health risk. Cadmium is a marked element for the application of chemical fertilisers and pesticides in agricultural production (Gray et al. 2019), and the long-term agricultural production in the studied region has resulted in the accumulation of Cd in soils. In addition, in order to increase productivities, chemical fertilisers and pesticides have been overused in some regions in Xin Jiang and the application of chemical fertilisers and pesticides in these regions is higher than the national average (Liu 2014). The utilisation efficiency of chemical fertilisers and pesticides in China is low (Turdi and Yang 2016), with about 70% being lost into soil, air, and water (Liu 2014). Furthermore, the studied areas belong to a typical coal-burning region, where emissions from transportation and fossil fuel combustion are also important sources of Cd pollution in surface soils. Due to an increase in total population and industrial development, the consumption of raw coal and the number of motor vehicles, the emission of Cd-containing aerosols is also presenting an increasing trend.

Due to its long biological half-life, cadmium is a hazardous trace element for humans. Even a small amount but continuous intake can lead to accumulation of Cd in human body, causing kidney problems or weakening of bones (Yousaf et al. 2016). Cadmium can also enter agroecosystems through mineral phosphate fertilisers, leading to an increase in plant-available Cd in agricultural soils (Wiggenhauser et al. 2016). Although cadmium is not a plant nutrient, plants can take up small amount of this metal, which consequently enters the food chain and ultimately affects human health (Liu et al. 2016). Zinc and Cu pollutants were evaluated as causes of mild pollution due to their low toxicity coefficients and low potential ecological hazards (Wang 2017). It is worth noting that soils in the agricultural and the pastoral areas have suffered from high Cd enrichment. Undoubtedly, Cd in the soil from Bai Cheng should be considered as the most harmful pollutant.

3.3 Potential health risk assessment of trace elements in surface soils in agricultural and pastoral areas

Seven heavy metals including Cd, Cr, As, Pb, Cu, Zn, and Ni were considered in the health risk assessment because of their relatively strong toxicity to humans and published dose-response relationships (Jiang et al. 2017). The daily average cancer exposure and risk assessment of As, Cd, Ni, Co, and Cr through dermal contact, ingestion, and inhalation exposure routes for adults (Table S7, S8, S9 and S10), as well as the exposure doses of trace elements in relation to adult non-carcinogenic risk through dermal contact, ingestion and inhalation exposure routes (Table S11, S12 and S13) in the agricultural and pastoral areas of Bai Cheng County were calculated using the parameters of US EPA health risk assessment method and the measured levels of trace elements. For both agricultural and pastoral areas, the main exposure route for carcinogenic and non- carcinogenic risks of trace elements were through ingestion by hand-to-mouth route, followed by skin contact route. The respiratory route caused the lowest exposure of carcinogenic risk and non- carcinogenic risk to human health, which is consistent with previous results (Mamut et al. 2017; Jiang et al. 2017).

Due to the lack of cancer slope factors for Pb, Zn and Cu, only carcinogenic risk indices for As, Cd, Cr, Co and Ni were estimated. According to available slope factors, all three pathways – dermal contact, ingestion, and inhalation – were contained in the risk estimation of As, but only one or two pathways were included in the estimation of other metals. On the basis of daily average exposure, combined with the carcinogenic risk assessment method, the carcinogenic risk quotient (CR) and total carcinogenic risk index (TCR) of trace elements in soils of agricultural and pastoral areas in the studied region were obtained using Eqs. (8) and (9). The results are listed in Table S11 and presented in Fig. 4. The risk of respiratory carcinogenesis caused by Cd, As, Ni, Cr, and Co through skin contact and hand-to-mouth intake was less than $1*10^{-4}$, being within the acceptable levels, and indicating no significant health effects.

The carcinogenic risk of Cr through hand-to-mouth intake was higher than $1*10^{-4}$, indicating that there was a cancer risk for Cr. The total cancer risk caused by these three routes was higher than $1*10^{-}4$, and thus there was a carcinogenic risk. The order of cancer exposure to trace elements in both agricultural and pastoral areas through skin contact, respiratory pathway, and oral intake is Cr>Ni>As>Co>Cd; the order of carcinogenic risk of elements through respiratory pathway is Cr>As>Co>Ni>Cd; and the order of carcinogenic risk of trace elements through hand-to-mouth intake is : Cr>Co>Ni>As>Cd. Chromium was the greatest contributor to the total carcinogenic risk from surface soils and the result was similar to that of the previous study (Zeng et al. 2019). Measures should be taken to reduce the potential carcinogenic risk. Although Cd was the main pollutant in soils, the concentration level of Cr in the surface soils was higher than that of Cd, thus the potential exposure level of Cr in the soil was higher than that of Cd.

On the basis of daily average exposure, combined with the non-carcinogenic risk assessment method, the non-carcinogenic risk quotient (HQ) and non-carcinogenic risk index (HI) of trace elements in soils of the agricultural and pastoral areas were obtained using Eqs. (6) and (7).

The results are listed in Table S14 and plotted in Fig. 5. These results showed that the HQ of trace elements in soils of the agricultural and animal husbandry areas in Bai Cheng County can be ordered as: As> Co>Cr> Pb> Mn>Ni>Cd>Cu >Co>Zn. Due to the high concentration or the low RFD values, As, Co, Cr and Pb posed higher potential non-carcinogenic risk to the residents. Based on the US EPA (2010) report, if HI< 1, the exposed individual was unlikely to experience obvious adverse health effects. On the contrary, if HI>1, there was the chance of a non-carcinogenic effect. Generally speaking, the HQ and HI of trace elements from soils through three exposure routes of the agricultural and pastoral areas in Bai Cheng County were less than 1, and the risk was relatively low, indicating an acceptable risk level. The result was consistent with that of the previous study (Saha et al. 2016).

Both the carcinogenic risk and non-carcinogenic risk derived from ingestion routes accounted for 99% of TCR and HI for adults, being much higher than the carcinogenic risks and non-carcinogenic risks derived from other pathways in total. This indirect pathway has not been considered in the health risk assessment of soils in most studies (Chen et al. 2016; Luo et al. 2015), which provide an underestimation of health risks of heavy metals in the soil. It may be considered reasonable to ignore this indirect pathway for a health risk assessment of urban soils as daily food products in cities come from supermarkets and consequently are grown elsewhere (Jiang et al. 2017). However, food such as rice and vegetables are planted and harvested to varying degrees in rural areas. Therefore, to assess the health risks of soil, the ingestion exposure pathway from the soil should be considered.

It should be recognised that the potential health risks of trace elements may have been over-estimated, considering the following aspects: Firstly, the potential health risks of trace elements were calculated by using the total concentration level of elements in the soil, however different forms of metals, including their biological accessibility and bioavailability, vary in the aspects of intake, absorption, transformation and exposure (Jiang et al. 2017). In addition, the potential exposure level to trace elements from the soil varys between different seasons, genders and ages (Tudi et al. 2019). Moreover, the cancer slope factor (CF) and RFD are different for varying genders and ages. However, these aspects were not considered in terms of the limitation of investigation in this study.

3.4 Source identification of trace elements in soils

Principle Component Analysis (PCA) was carried out for the surface soil layer (0–5cm) in typical agricultural and pastoral soils in Bai Cheng County. The results are shown in Table 2. The eigenvalues larger than 1 were extracted. Three principal components (PC) were obtained from both agricultural area and pastoral area.

In the agricultural area, Cr, Cu, Mn, Ni, and Fe in soils had good negative correlations with the first principal component (PC1). The second principal component (PC2) was dominated by Co, Li, Zn, Mo, and Se. The third principal component (PC3) significantly related with Cd, As, and Pb. PC1 accounted for 30.50% of the total variation. In addition, the average level of these elements was slightly higher than their background values and lower than that of the Environmental Quality Standard of China (GB15618-1995). Furthermore, previous studies showed that elements such as Cr, Ni, Cu and Mn in soil are mainly influenced by geochemical origin and are mainly derived from geological sources (Mamat et al. 2014; Šajn et al. 2010). Thus, the PC1 mainly derives from natural sources and slightly anthropogenic sources such as traffic sources. For PC2, the mean levels of Li, Zn, and Mo, were higher than their background values. Thus, the metals in PC2 might be mainly derived from agricultural activities and atmospheric deposition. In PC3, the mean contents of Cd, Pb, and As were much higher than their background values. Previous studies suggested that As mainly derived from human activities, such as the use of pesticides and fertilisers (Si et al. 2015). Cadmiumand Pb can be used as marked elements of the usage of pesticides and fertilisers (Abbas et al. 2017). Thus, the metals in PC3 are mainly derived from agricultural sources.

In the pastoral areas, PC1 mainly contained Co, Cr, Cu, Mn, Mo, and Fe at a soil depth of 0–5 cm. PC2 was significantly correlated with Li, Pb, Cd, and Ni. PC3 was dominated by Zn, Se, and As. The mean levels of Co, Cr, Cu, Mn, As and Fe at a soil depth of 0–5 cm of typical pastoral soils similar to their background levels in soils from Xin Jiang. Therefore, PC1 was mainly influenced by the geochemical background characteristics and geological factors. For PC2, the average level of Cd exceeded the China National Soil Second Standard Level (GB15618-1995), indicating serious pollution caused by Cd. In addition, its source was also affected by human factors. Furthermore, the average levels of Pb and Ni were higher than their background levels. Therefore, the sources of the metals in PC2 were mainly influenced by human factors. A relevant study indicated that the concentration levels of Ni, Cd and Pb in the soil are influenced by atmospheric deposition (Li et al 2014). Therefore, Ni, Li, Cd, and Pb might be also from atmospheric deposition. In PC3, The mean levels of Zn and As in the pastoral areas were higher than their background values, indicating that they were influenced by human factors, particularly atmospheric deposition.

4 Conclusions

The results of this study indicated that Cd was the main pollutant at a soil depth of 0–5cm in both agricultural and pastoral areas. Thus, it substantially contributed to the Geo-Accumulation Index (I*geo*) and the comprehensive potential ecological risk (RI) of the soil. Generally, the RI for the surface soil layer of the agriculture areas fell into the moderate to high (II-III) ecological risk category; that of the pastoral areas fell into the low-moderate risk category (I-II). The pollution index of the soil in agriculture areas was higher than in the pastoral areas.

There is a certain homologous relationship or compound pollution among the trace elements in both agricultural and pastoral areas. Trace elements in Bai Cheng revealed the main characteristics of the geochemical background, but were further influenced by human factors including agricultural activities, transportation, mining in nearby areas and atmospheric deposition.

Whether for agricultural or pastoral areas, in relation to cancer risks, the main exposure route of trace elements in the soil was hand-to-mouth ingestion, followed by skin contact and subsequently respiration. The carcinogenic risk of Cr through hand-to-mouth intake and the total risk of trace elements in the soil by these three routes were higher than the safety reference level (1*10-4). Thus, Cr was the most significant contributor to total carcinogenic risk.

The authors declare that they have no conflict of interest, financial or other. This article does not contain any studies involving human participants or animals.

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References

Abbas Q et al (2017) Evaluating the health risks of potentially toxic elements through wheat consumption in multi-industrial metropolis of Faisalabad, Pakistan. Environ Sci Pollut Res 24(34):26646-26657

Abdelhafez AA, Li JH (2015) Environmental Monitoring of Heavy Metal Status and Human Health Risk Assessment in the Agricultural Soils of the Jinxi River Area, China. Human Ecol Risk Assess21(4):952-971

Amorosi A, et al (2014) Fingerprinting sedimentary and soil units by their natural metal contents: A new approach to assess metal contamination. Sci Total Environ 500:361-372

Chen HY et al (2016)Characteristics of heavy metal transfer and their influencing factors in different soil-crop systems of the industrialization region, China. Ecotox Environ Saf 126:193-201

Cheng L (2009) Evaluation of the potential regional land resource based on GIS -- A case study of Baicheng Xinjiang University

Doabi SA et al (2018) Pollution and health risk assessment of heavy metals in agricultural soil, atmospheric dust and major food crops in Kermanshah province, Iran. Ecotox Environ Saf 163:153-164

Liu JJ et al (2015) Heavy metals contents and speciation in surface sediments from Gansu, Ningxia and Inner Mongolia sections of the Yellow River of China. Spectrosc Spect Anal 35(10):2963-2969

Liu RQ et al (2018) Ecological risk assessment and distribution of potentially harmful trace elements in lake sediments of Songnen Plain, NE China. Ecotox Environ Safe 163:117-124

Liu Z et al (2016) The effect of municipal sludge compost on the mobility and bioavailability of Cd in a sierozem-wheat system in an arid region northwest of China. Environ Sci Pollut Res 23(20):20232-20242

Mamut A, Eziz M, Mohammad A (2018) Pollution and ecological risk assessment of hemvy metals in Farmland soils in Yanqi County, Xinjiang, Northwest China. Eurasian Soil Sci 51(8):985-993

Mamut A et al (2017) Contamination and risk assessment of heavy metals in farmland soils of Baghrash County, Xinjiang, Northwest China. Sci Cold Arid Reg 9(5):467-475

Mora A et al (2009)Survey of trace metals in drinking water supplied to rural populations in the eastern Llanos of Venezuela. J Environ Manage 90(2):752-759

Pan ZX (2013) Evaluation of the suitibality of urban construction land based on GIS-A case study of Baicheng Xinjiang University

Ramdani, M., Elkhiati, N., & Flower, R. J. (2009). Lakes of Africa: North of Sahara. , Editor(s): Gene E. Likens, Encyclopedia of Inland Waters, Academic Press, pages 544-554.

Saha N et al (2016) Spatial distribution and contamination assessment of six heavy metals in soils and their transfer into mature tobacco plants in Kushtia District, Bangladesh. Environ Sci Pollut Res 23(4):3414-3426

Shen ZJ, Chen YS, Zhang Z (2017) Heavy metals translocation and accumulation from the rhizosphere soils to the edible parts of the medicinal plant Fengdan (Paeonia ostii) grown on a metal mining area, China. Ecotoxicol Environ Safe 143:19-27

Turdi M, Yang LS (2016) Trace elements contamination and human health risk assessment in drinking water from the agricultural and pastoral areas of Bay County, Xinjiang, China. Int J Env Res Pub He13(10):938DOI: 10.3390/ijerph13100938

Wiggenhauser M et al (2016) Cadmium Isotope Fractionation in Soil-Wheat Systems. Environ Sci Technol 50(17):9223-9231

Yousaf B et al (2016) Investigating the potential influence of biochar and traditional organic amendments on the bioavailability and transfer of Cd in the soil-plant system. Environ Earth Sci 75(5):374

Zeng XX et al (2015)Spatial distribution, health risk assessment and statistical source identification of the trace elements in surface water from the Xiangjiang River, China. Environ Sci Pollut Res 22(12):9400-9412

Zhang ZX et al (2019) Risk assessment, spatial distribution, and source identification of heavy metal (loid)s in paddy soils along the Zijiang River basin, in Hunan Province, China. J Soils Sediments 19(12):4042-4051

Zhang H et al (2017) Level, source identification, and risk analysis of heavy metal in surface sediments from river-lake ecosystems in the Poyang Lake, China. Environ Sci Pollut Res 24(27):21902-21916

Zhang S et al (2016) Health risk assessment of heavy metals in groundwater of coal mining area: A case study in Dingji coal mine, Huainan coalfield, China. Hum Ecol Risk Assess 22(7):1469-1479

Zhang WX et al (2018) Seasonal variations of mercury levels and human health risk in vegetables from Arid Oasis (Shihezi city), Xinjiang, Northwest China. Hum Ecol Risk Assess 24(1):122-136

Zheng J et al (2013) Heavy metals in food, house dust, and water from an e-waste recycling area in South China and the potential risk to human health. Ecotox Environ Safe 96:205-212

Zhu L et al (2017) Deposition behavior, risk assessment and source identification of heavy metals in reservoir sediments of Northeast China. Ecotox Environ Safe142:454-463

Table 1Potentail Igeo pollution index of 0-5 cm Soil

AGR	N	Mean	SD	Min	Max	Skew	Kurtosis	SE
Cr	160	-0.368	0.435	-1.078	0.361	0.079	-1.396	0.089
Co		-1.229	0.349	-1.746	-0.598	0.422	-1.05	0.071
Ni		0.032	0.464	-0.773	0.845	0.061	-0.839	0.095
Cd		1.327	0.873	0.278	3.462	0.831	-0.447	0.178
Pb		-0.09	0.423	-0.693	0.842	0.724	-0.436	0.086
Cu		-0.502	0.351	-1.18	0.343	0.215	0.296	0.072
Mn		-0.703	0.15	-0.982	-0.438	-0.35	-0.928	0.031
Zn		0.151	0.831	-0.709	2.837	2.049	3.813	0.17
As		-0.062	0.342	-0.779	0.796	-0.004	-0.407	0.049
PST		Mean	SD	Min	Max	Skew	Kurtosis	SE
Cr	40	-0.504	0.462	-2.187	-0.038	-2.395	6.037	0.103
Co		-1.443	0.595	-2.491	-0.72	-0.362	-1.562	0.133
Ni		-0.876	1.826	-5.086	0.49	-1.57	0.708	0.373
Cd		1.029	0.999	-1.081	2.661	-0.26	-0.854	0.223
Pb		-0.467	0.294	-1.067	0.138	-0.036	-0.466	0.066
Cu		-0.628	0.292	-1.597	-0.158	-1.544	3.552	0.065
Mn		-0.723	0.152	-1.11	-0.475	-0.467	0.129	0.034
Zn		0.231	0.288	-0.535	0.856	-0.58	1.106	0.064
As		-0.158	0.543	-1.927	0.567	-1.46	3.176	0.121

Table 2 Principal component characteristic vector and principal component factor （PC） load analysis of soil trace elements in different areas of Bai Cheng County

Agriculture areas	PC1	PC2	PC3
Eigenvalue	3.964465	2.958225	1.925451
% Total	30.4959	53.2515	68.0626
Cd	-0.630845	-0.166336	0.672483
Co	-0.158446	0.756849	-0.355418
Cr	-0.751775	0.493956	-0.179136
Cu	-0.899458	0.026368	-0.210051
Li	-0.480751	-0.655482	0.023468
Mn	-0.590359	0.247496	0.151714
Zn	0.018660	-0.491776	-0.385575
Pb	-0.559962	0.171767	0.669930
Mo	-0.558531	-0.684646	0.108382
Ni	-0.683765	-0.359918	-0.424112
Se	0.070678	-0.769527	-0.381245
As	0.000081	0.233064	-0.311034
Fe	-0.699406	0.325604	-0.464688
Pasture areas	PC1	PC2	PC3
Eigenvalue	4.641619	3.427236	1.764570
% Total	35.7048	62.0681	75.6417
Cd	-0.516961	0.693487	0.407206
Co	0.944951	-0.126358	-0.098117
Cr	0.777451	0.493746	-0.171077
Cu	0.863114	0.366261	0.035089
Li	0.117339	0.701636	0.016344
Mn	0.591279	0.262079	0.270700
Zn	0.099835	0.459623	-0.779102
Pb	0.076714	0.916474	0.259131
Mo	-0.642810	0.527094	-0.307823
Ni	-0.535585	0.633845	0.150547
Se	0.025588	0.132178	0.673899
As	-0.448637	0.392473	-0.486159
Fe	0.922401	0.298603	-0.054992

Figure 1 Sampling points

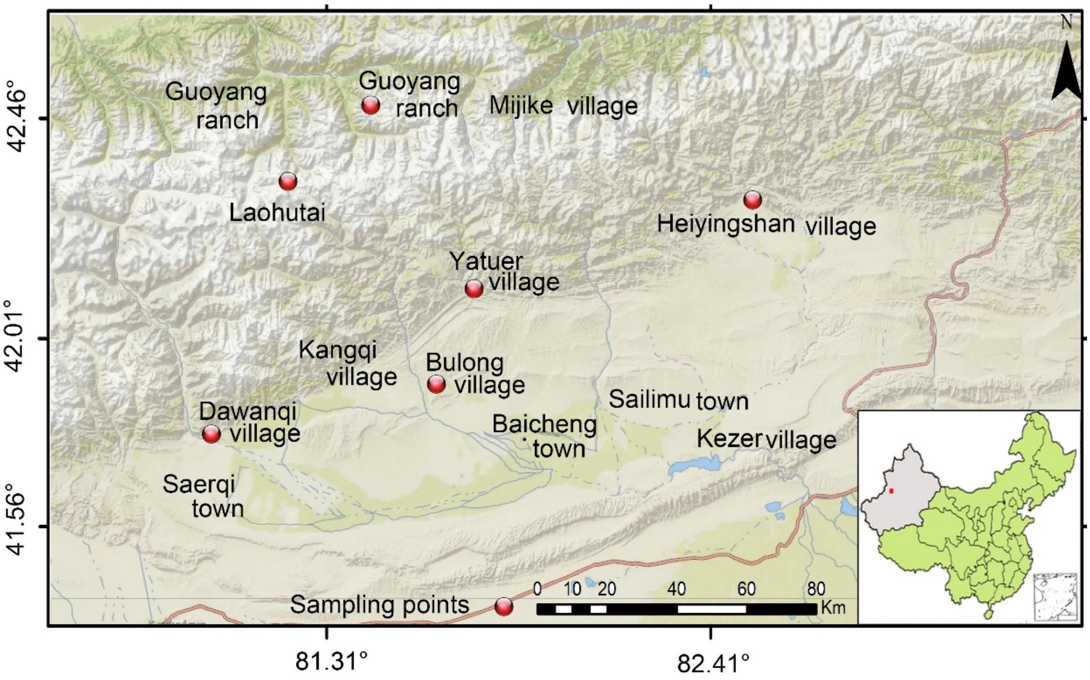
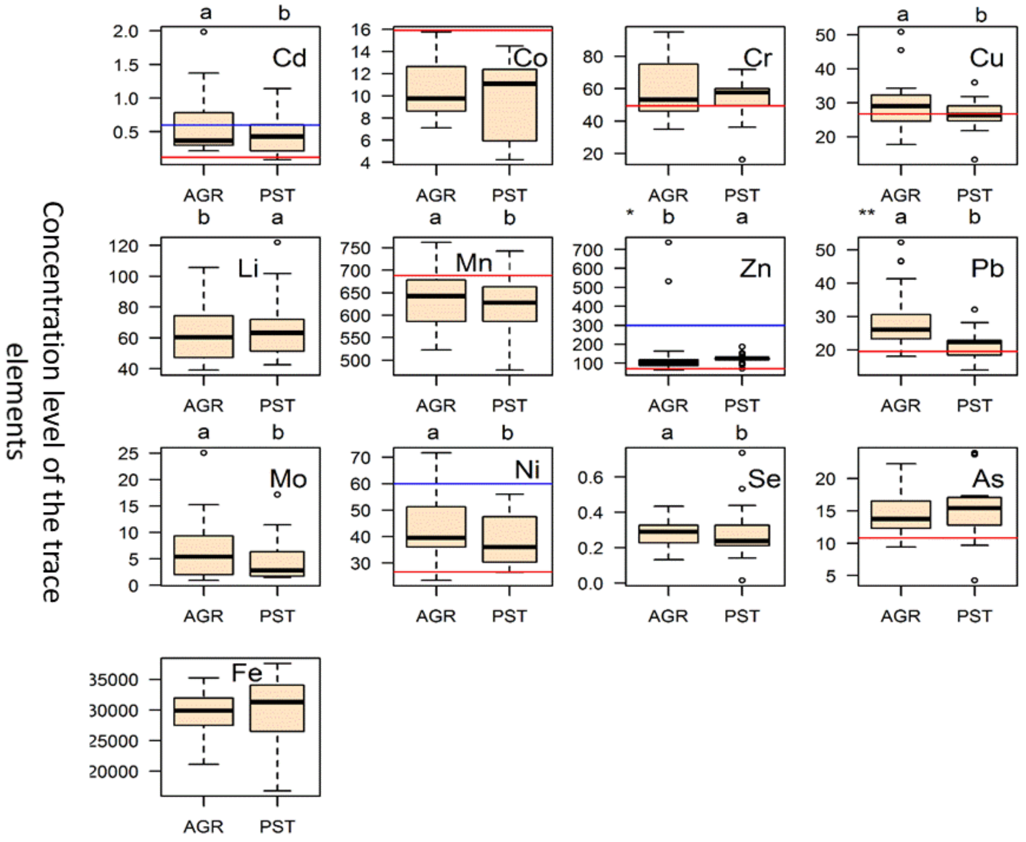


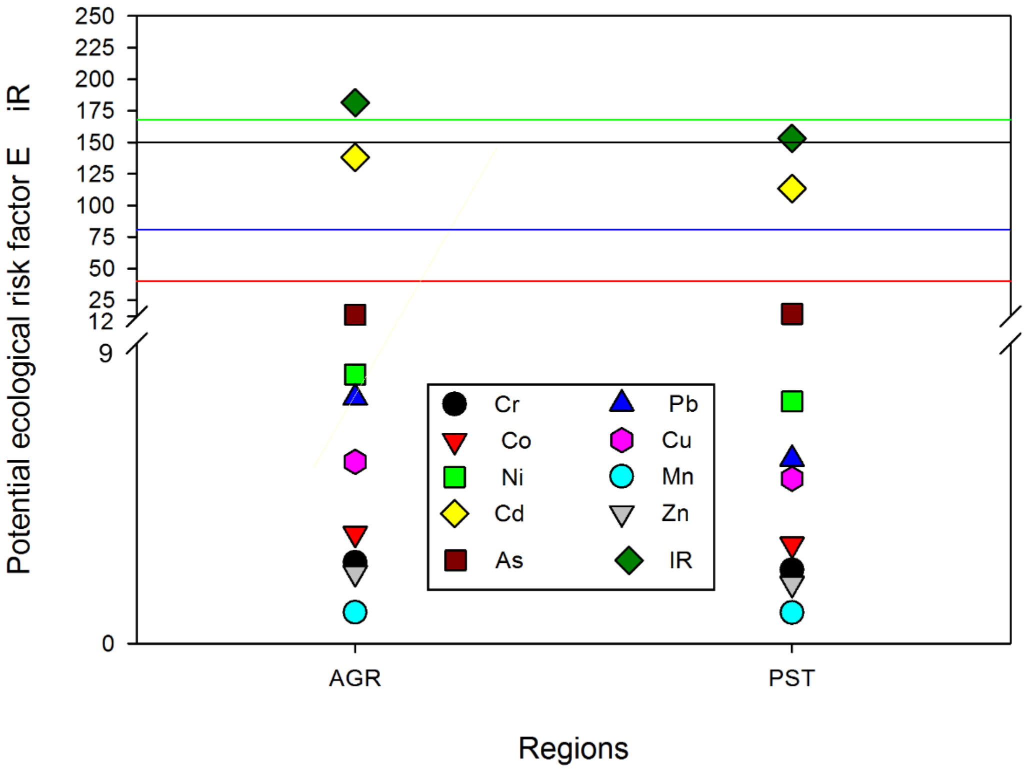
Figure2 Box-whisker diagrams showing metal concentrations in 0-5cm soil (unit: mg/kg)



Note: AGR: agriculture areas; n: 160. PST: Pastoral areas: n: 80

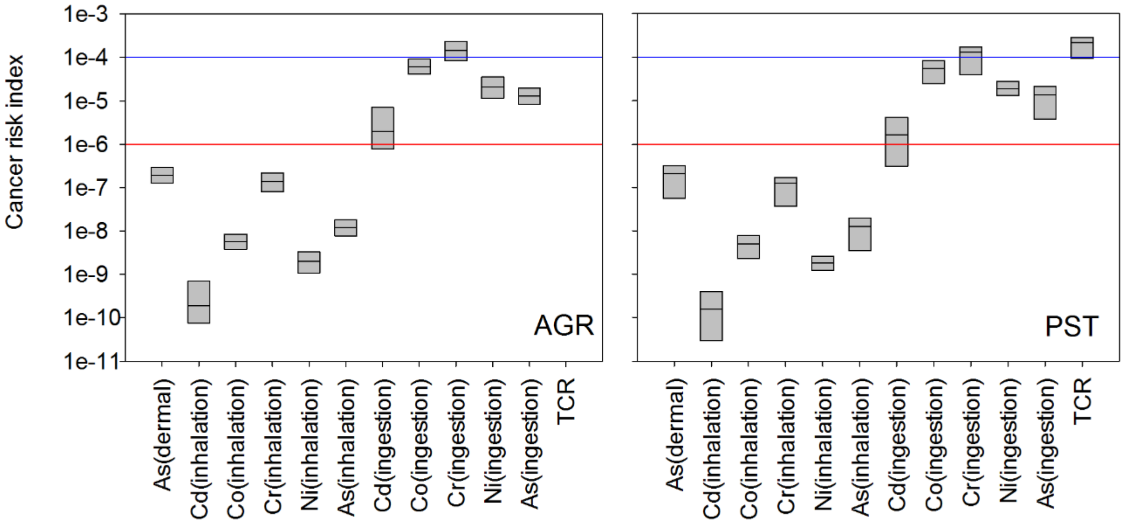
In this study a and b are used to indicate the results of the Tukey-HSD and non-parametric methods which are used to compare the concentration level of trace elements.

Figure3 Potential Ecological Risk Index of Trace Elements in Soil



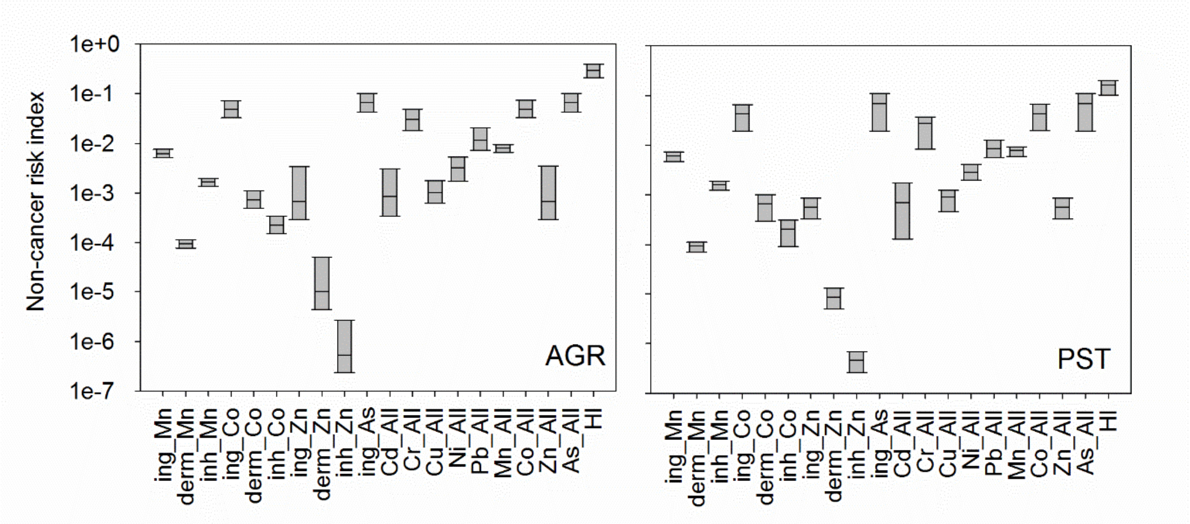
Note: n: 160 (AGR); n: 80 (PST).

Figure4 Potential Cancer Risk Index of trace elements from Soils



Note: n: 160 (AGR); n: 80 (PST).

Figure 5 Potential Non-Cancer Risk Index of Trace elements in Soils



Note: n: 160 (AGR); n: 80 (PST).

Table S1 Background value of the Xin Jiang Soil and Environmental Quality Standard of China (GB15618-1995) (pH>7.5)

	Cd	Co	Cr	Cu	Ni	Pb	Zn	As	Mn
Background value of the Xinjiang Soil	0.12	15.9	49.3	26.7	26.6	19.4	68.8	10.78	688
Environmental Quality Standard of China (GB15618-1995)	0.6	-----	250	100	60	350	300	25.0	------

Table S2 Parameters and Values of Potential Health Risk Assessment Models

Reference	Unit		value	Reference	Unit		Value
EF	d-a-1	frequency of exposure	300	IngR	mg/d	Ingestion rate	100
ED	a	year of exposure	30	InhR	M3/d	inhalation rate	12.8
CF	kg.mg-1	Conversion coefficient	1e-6	AT (non-cancer)	d	exposure time	10950
BW	kg	average weight	60	AT（cancer)	d	exposure time	25550
SL	mg.m2	Skin Adhesion degree	0.07	PFE	M3/kg	emission factor	1.36E+09
SA	m3.d-1	Skin area	4350	ABS		Skin absorption factor	0.001

Table S3 Referenced Doses of RfD and SF in different Exposure Routes of Trace Elements

Reference	Zn	Cu	Cr	Pb	Hg	As
*RfD*ing	3e-01	4e-02	3e-03	3.5e-04	3e-04	3e-04
RfDinh	3e-01	4e-02	2.86e-05	3.52e-03	1.5e-05	1.23e-04
*RfD*derm	6e-02	1.2e-02	6e-05	5.25e-04	8.6e-05	3e-04
*SF*ing	---	-----	-------	-----	-----	1.5
SFinh	----	------	42.0	------	------	1.5
SFderm	---	------	-------	0.0085	------	7.5

Table S4 Descriptive statistics of trace elements of 0-5 cm soil in different sections of Bay County (Unit: mg·kg^{-1}; KYR, KRW, DW, YTR, YC, B, All, AGR and PST strand for Heiyingshan, Laohutai, Dawanqi, Yaturi, Yangchang , Bulong, Bay, Agricultural areas, Pastoral areas)

AGR	n	mean	sd	min	max	skew	kurtosis	se	cv
Li	160	62.363	17.777	39.09	105.6	0.767	-0.166	3.629	0.285
Cr		59.836	18.092	35.03	94.953	0.375	-1.274	3.693	0.302
Co		10.477	2.661	7.11	15.752	0.714	-0.779	0.543	0.254
Ni		42.881	14.005	23.342	71.648	0.623	-0.608	2.859	0.327
Mo		6.522	5.832	0.903	25.046	1.42	1.849	1.19	0.894
Cd		0.553	0.426	0.218	1.983	1.831	3.036	0.087	0.770
Pb		28.573	9.35	18.006	52.166	1.16	0.211	1.909	0.327
Cu		29.107	7.448	17.68	50.79	1.077	1.529	1.52	0.256
Fe		29396.13	3634.917	21119	35238	-0.478	-0.416	741.974	0.124
Mn		637.309	65.022	522.4	761.711	-0.185	-0.94	13.273	0.102
Zn		145.537	155.532	63.15	737.545	2.898	7.352	31.748	1.069
Se		0.254	0.085	0.09	0.434	0.357	-0.614	0.011	0.335
As		15.923	3.808	9.423	28.08	0.629	0.495	0.544	0.239
PST	80	mean	sd	min	max	skew	kurtosis	se	cv
Li		65.258	19.868	42.49	122	1.307	1.19	4.443	0.304
Cr		54.164	12.386	16.24	72.025	-1.371	2.067	2.77	0.229
Co		9.457	3.506	4.242	14.477	-0.142	-1.738	0.784	0.371
Ni		32.393	16.666	1.175	56.048	-0.654	-0.519	3.402	0.514
Mo		4.595	4.059	1.435	17.141	1.616	2.125	0.908	0.883
Cd		0.453	0.293	0.085	1.139	0.903	0.032	0.066	0.647
Pb		21.478	4.391	13.888	32.014	0.472	-0.124	0.982	0.204
Cu		26.367	4.675	13.24	35.894	-0.607	1.276	1.045	0.177

Fe		30124.85	5113.134	16779	37632	-0.73	0.058	1143.332	0.169
Mn		628.29	64.569	478	742.7	-0.166	-0.268	14.438	0.103
Zn		123.399	23.768	71.23	186.8	0.311	1.183	5.315	0.193
Se		0.286	0.153	0.014	0.737	1.203	1.778	0.034	0.535
All	240	mean	sd	min	max	skew	kurtosis	se	cv
Li		63.679	18.589	39.09	122	1.115383	0.956	2.802	0.292
Cr		57.257	15.843	16.24	94.952	0.184	0.061	2.388	0.277
Co		10.013	3.0791	4.242	15.751	0.027	-0.977	0.464	0.308
Ni		37.637	16.124	1.174	71.64	-0.303	0.397	2.327	0.428
Mo		5.646	5.139	0.902	25.046	1.671	2.953	0.774	0.910
Cd		0.5074	0.370	0.085	1.983	1.849	3.986	0.055	0.730
Pb		25.348	8.249	13.88	52.165	1.554	2.187	1.243	0.325
Cu		27.86	6.421	13.24	50.79	1.057	3.062	0.968	0.230
Fe		29727.36	4330.589	16779	37632	-0.619	0.290	652.860	0.146
Mn		633.209	64.220	478	761.710	-0.178	-0.524	9.681	0.101
Zn		135.474	115.381	63.15	737.544	4.116	17.041	17.394	0.852
Se		0.262	0.1068	0.014	0.737	1.277	3.845	0.0121	0.408
As		15.756	4.082	4.253	28.080	0.350	0.641	0.491	0.259

Table S5 Trace elements in 0-5 cm soils tested by Shaprino Normality

region	n	stat	P.value	variable	Test. type	test.result
AGR	160	0.92116	0.061964	Li	actual	normal
		0.958623	0.411388	Li	Log-transformed	normal
		0.924192	0.072347	Cr	actual	normal
		0.941899	0.179804	Cr	Log-transformed	normal
		0.897659	0.019206	Co	actual	NOT
		0.93713	0.140748	Co	Log-transformed	NOT
		0.918123	0.053096	Ni	actual	normal
		0.951954	0.298515	Ni	Log-transformed	normal
		0.839975	0.001432	Mo	actual	NOT
		0.965511	0.55855	Mo	Log-transformed	NOT
		0.734109	2.94E-05	Cd	actual	NOT
		0.891921	0.014567	Cd	Log-transformed	NOT
		0.834168	0.001127	Pb	actual	NOT
		0.908448	0.032643	Pb	Log-transformed	NOT
		0.895531	0.017326	Cu	actual	NOT
		0.953601	0.323639	Cu	Log-transformed	NOT
		0.961051	0.459901	Fe	actual	normal
		0.935907	0.132158	Fe	Log-transformed	normal
		0.968559	0.631534	Mn	actual	normal
		0.958192	0.40318	Mn	Log-transformed	normal
		0.466312	2.7E-08	Zn	actual	NOT
		0.719193	1.83E-05	Zn	Log-transformed	NOT
		0.954527	0.031677	Se	actual	NOT
		0.952873	0.02659	Se	Log-transformed	NOT
		0.965341	0.156998	As	actual	normal
		0.986983	0.859727	As	Log-transformed	normal
PST		0.857435	0.007119	Li	actual	NOT
		0.934545	0.188786	Li	Log-transformed	NOT

	80	0.857598	0.007165	Cr	actual	NOT
		0.690085	2.96E-05	Cr	Log-transformed	NOT
		0.880119	0.01778	Co	actual	NOT
		0.871864	0.012672	Co	Log-transformed	NOT
		0.884685	0.010339	Ni	actual	NOT
		0.628969	1.32E-06	Ni	Log-transformed	NOT
		0.76942	0.000313	Mo	actual	NOT
		0.910994	0.066578	Mo	Log-transformed	NOT
		0.901313	0.043647	Cd	actual	NOT
		0.972195	0.800388	Cd	Log-transformed	NOT
		0.939697	0.236641	Pb	actual	normal
		0.956948	0.484818	Pb	Log-transformed	normal
		0.941189	0.252487	Cu	actual	normal
		0.849757	0.005281	Cu	Log-transformed	normal
		0.945793	0.307702	Fe	actual	normal
		0.885844	0.022572	Fe	Log-transformed	normal
		0.969928	0.753362	Mn	actual	normal
		0.959334	0.530623	Mn	Log-transformed	normal
		0.877054	0.015667	Zn	actual	NOT
		0.869428	0.01148	Zn	Log-transformed	NOT
		0.869452	0.011492	Se	actual	NOT
		0.719904	6.89E-05	Se	Log-transformed	NOT
		0.927895	0.140653	As	actual	normal
		0.838521	0.003444	As	Log-transformed	normal

Table S6 of Trace elements non-parametric correlation analysis

AGR	Li	Cr	Co	Ni	Mo	Cd	Pb	Cu	Fe	Mn	Zn	Se	As
Li	1												
Cr	0.618**	1											
Co	-0.176	-0.036	1										
Ni	0.062	0.42*	0.049	1									
Mo	0.683**	0.436*	-0.074	0.101	1								
Cd	0.87**	0.487*	-0.308	0.191	0.642**	1							
Pb	0.726**	0.577**	-0.341	0.313	0.457*	0.873**	1						
Cu	0.379	0.441*	-0.189	0.705**	0.198	0.463*	0.499*	1					
Fe	0.151	0.442*	0.152	0.505*	0.001	-0.098	0.062	0.52**	1				
Mn	0.091	0.232	0.225	0.308	-0.038	-0.139	-0.012	0.393	0.836**	1			
Zn	0.469*	0.47*	-0.116	0.118	0.149	0.452*	0.606**	0.315	0.304	0.252	1		
Se	0.228	-0.148	0.086	-0.355	0.126	0.011	-0.041	-0.124	0.129	0.41*	0.123	1	
As	-0.456*	-0.279	0.26	0.113	0.008	-0.281	-0.158	-0.144	0.039	0.081	-0.07	-0.21	1
Pastoral	Li	Cr	Co	Ni	Mo	Cd	Pb	Cu	Fe	Mn	Zn	Se	As
Li	1												
Cr	0.514*	1											
Co	0.334	0.619**	1										
Ni	0.141	0.511*	0.729**	1									
Mo	0.866**	0.238	0.133	-0.053	1								
Cd	0.542*	0.121	0.295	0.175	0.539*	1							
Pb	0.508*	0.501*	0.761**	0.548*	0.432	0.697**	1						
Cu	0.456*	0.616**	0.856**	0.591**	0.226	0.501*	0.78**	1					
Fe	0.248	0.813**	0.8**	0.655**	0.009	0.142	0.651**	0.729**	1				
Mn	0.072	0.549*	0.611**	0.525*	-0.015	0.149	0.563*	0.378	0.775**	1			
Zn	0.465*	0.381	0.201	0.14	0.512*	-0.062	0.292	0.262	0.224	-0.019	1		
Se	0.298	0.108	0.028	-0.096	0.098	0.061	0.223	0.154	0.033	0.029	0.361	1	
As	-0.326	-0.218	-0.26	0.055	-0.118	0.048	-0.036	-0.246	-0.202	-0.068	-0.07	-0.207	1

Table S7 Average Daily Exposure for Carcinogenic Risk of Trace Elements in Soils through Dermal Contact

Agriculture areas	Cd	Co	Cr	Ni	As
n	160	160	160	160	160-
Mean	9.89E-10	1.87E-08	1.07E-07	7.67E-08	2.6E-08
Standard Deviation	7.61E-10	4.76E-09	3.23E-08	2.5E-08	6.28E-09
Kurtosis	4.745048	-0.42526	-1.09658	-0.19328	-0.37025
Skewness	2.084436	0.813166	0.42728	0.708922	0.649279
Minimum	3.9E-10	1.27E-08	6.26E-08	4.17E-08	1.68E-08
Maximum	3.55E-09	2.82E-08	1.7E-07	1.28E-07	3.98E-08
Pasture areas	Cd	Co	Cr	Ni	As
n	80	80	80	80	80
Mean	8.1E-10	1.69E-08	9.68E-08	6.9E-08	2.74E-08
Standard Deviation	5.24E-10	6.27E-09	2.21E-08	1.74E-08	8.53E-09
Kurtosis	0.841846	-1.71624	3.781131	-1.21313	0.964177
Skewness	1.055603	-0.16656	-1.60325	0.508709	0.069209
Minimum	1.52E-10	7.58E-09	2.9E-08	4.73E-08	7.6E-09
Maximum	2.04E-09	2.59E-08	1.29E-07	1E-07	4.28E-08

Table S8 Average Daily Exposure for potential Carcinogenic Risk of trace elements in Soils through Inhalation

Agriculture areas	*Cd*	*Co*	*Cr*	*Ni*	*As*
n	160	160	160	160	160
Mean	3.06E-11	5.79E-10	3.31E-09	2.37E-09	8.03E-10
Standard Deviation	2.35E-11	1.47E-10	1E-09	7.74E-10	1.94E-10
Kurtosis	4.745048	-0.42526	-1.09658	-0.19328	-0.37025
Skewness	2.084436	0.813166	0.42728	0.708922	0.649279
Minimum	1.21E-11	3.93E-10	1.94E-09	1.29E-09	5.21E-10
Maximum	1.1E-10	8.7E-10	5.25E-09	3.96E-09	1.23E-09
Pasture areas	*Cd*	*Co*	*Cr*	*Ni*	*As*
n	80	80	80	80	80
Mean	2.5E-11	5.23E-10	2.99E-09	2.13E-09	8.48E-10
Standard Deviation	1.62E-11	1.94E-10	6.84E-10	5.36E-10	2.64E-10
Kurtosis	0.841846	-1.71624	3.781131	-1.21313	0.964177
Skewness	1.055603	-0.16656	-1.60325	0.508709	0.069209
Minimum	4.7E-12	2.34E-10	8.97E-10	1.46E-09	2.35E-10
Maximum	6.29E-11	8E-10	3.98E-09	3.1E-09	1.32E-09

Table S9 Average Daily Exposure for Potential Carcinogenic Risk of Trace Elements in Soils through Ingestion

Agriculture area	Cd	Co	Cr	Ni	As
n	160	160	160	160	160
Mean	3.25E-07	6.15E-06	3.51E-05	2.52E-05	8.53E-06
Standard Deviation	2.5E-07	1.56E-06	1.06E-05	8.22E-06	2.06E-06
Kurtosis	4.745048	-0.42526	-1.09658	-0.19328	-0.37025
Skewness	2.084436	0.813166	0.42728	0.708922	0.649279
Minimum	1.28E-07	4.17E-06	2.06E-05	1.37E-05	5.53E-06
Maximum	1.16E-06	9.25E-06	5.57E-05	4.21E-05	1.31E-05
Pasture area	Cd	Co	Cr	Ni	As
n	80	80	80	80	80
Mean	2.66E-07	5.55E-06	3.18E-05	2.27E-05	9.01E-06
Standard Deviation	1.72E-07	2.06E-06	7.27E-06	5.7E-06	2.8E-06
Kurtosis	0.841846	-1.71624	3.781131	-1.21313	0.964177
Skewness	1.055603	-0.16656	-1.60325	0.508709	0.069209
Minimum	5E-08	2.49E-06	9.53E-06	1.55E-05	2.5E-06
Maximum	6.68E-07	8.5E-06	4.23E-05	3.29E-05	1.41E-05

Table S10 Potential Cancer Risk Assessment of Trace Elements in 0-5 cm Soils

Agriculture area	As dermal	Cd inhalation	Co inhalation	Cr inhalation	Ni inhalation	As inhalation	Cd ingestion	Co ingestion	Cr ingestion	Ni ingestion	As ingestion	TCR
Mean	1.95E-07	1.93E-10	5.67E-09	1.39E-07	1.99E-09	1.20E-08	1.98E-06	6.03E-05	1.44E-04	2.11E-05	1.28E-05	2.41E-04
Standard error	9.61E-09	3.03E-11	2.94E-10	8.57E-09	1.33E-10	5.94E-10	3.11E-07	3.12E-06	8.89E-06	1.41E-06	6.31E-07	1.14E-05
Standard deviation	4.71E-08	1.48E-10	1.44E-09	4.20E-08	6.50E-10	2.91E-09	1.53E-06	1.53E-05	4.35E-05	6.91E-06	3.09E-06	5.58E-05
Minimum	1.26E-07	7.60E-11	3.85E-09	8.13E-08	1.08E-09	7.81E-09	7.82E-07	4.09E-05	8.43E-05	1.15E-05	8.30E-06	1.62E-04
Maximum	2.99E-07	6.90E-10	8.53E-09	2.20E-07	3.33E-09	1.85E-08	7.10E-06	9.06E-05	2.29E-04	3.53E-05	1.96E-05	3.34E-04
Pasture area	As dermal	Cd inhalation	Co inhalation	Cr inhalation	Ni inhalation	As inhalation	Cd ingestion	Co ingestion	Cr ingestion	Ni ingestion	As ingestion	TCR
Mean	2.06E-07	1.58E-10	5.12E-09	1.26E-07	1.79E-09	1.27E-08	1.62E-06	5.44E-05	1.30E-04	1.90E-05	1.35E-05	2.19E-04
Standard error	1.43E-08	2.28E-11	4.24E-10	6.43E-09	1.01E-10	8.84E-10	2.35E-07	4.51E-06	6.67E-06	1.07E-06	9.40E-07	9.36E-06

Standard deviation	6.40E-08	1.02E-10	1.90E-09	2.87E-08	4.51E-10	3.95E-09	1.05E-06	2.02E-05	2.98E-05	4.79E-06	4.20E-06	4.19E-05
Minimum	5.70E-08	2.96E-11	2.30E-09	3.77E-08	1.23E-09	3.53E-09	3.05E-07	2.44E-05	3.91E-05	1.31E-05	3.75E-06	9.49E-05
Maximum	3.21E-07	3.96E-10	7.84E-09	1.67E-07	2.60E-09	1.99E-08	4.08E-06	8.33E-05	1.73E-04	2.76E-05	2.11E-05	2.85E-04

Table S11 Average Daily Exposure for Potential Non-carcinogenic Risk of Trace Elements in Soils of the Study Area through Dermal Contact

Agriculture	Li	Cr	Co	Ni	Mo	Cd	Pb	Cu	Fe	Mn	Zn	Se	As
Mean	2.6E-07	2.5E-07	4.37E-08	1.79E-07	2.72E-08	2.31E-09	1.19E-07	1.21E-07	0.000123	2.66E-06	6.07E-07	1.17E-09	6.06E-08
Standard error	1.51E-08	1.54E-08	2.27E-09	1.19E-08	4.97E-09	3.63E-10	7.96E-09	6.34E-09	3.09E-06	5.54E-08	1.32E-07	6.37E-11	2.99E-09
Standard deviation	7.42E-08	7.55E-08	1.11E-08	5.84E-08	2.43E-08	1.78E-09	3.9E-08	3.11E-08	1.52E-05	2.71E-07	6.49E-07	3.12E-10	1.46E-08
Minimum	1.63E-07	1.46E-07	2.97E-08	9.74E-08	3.77E-09	9.1E-10	7.51E-08	7.37E-08	8.81E-05	2.18E-06	2.63E-07	5.51E-10	3.93E-08
Maximum	4.4E-07	3.96E-07	6.57E-08	2.99E-07	1.04E-07	8.27E-09	2.18E-07	2.12E-07	0.000147	3.18E-06	3.08E-06	1.81E-09	9.29E-08
Pasture	Li	Cr	Co	Ni	Mo	Cd	Pb	Cu	Fe	Mn	Zn	Se	As
Mean	2.72E-07	2.26E-07	3.94E-08	1.61E-07	1.92E-08	1.89E-09	8.96E-08	1.1E-07	0.000126	2.62E-06	5.15E-07	1.19E-09	6.4E-08
Standard error	1.85E-08	1.16E-08	3.27E-09	9.06E-09	3.79E-09	2.73E-10	4.1E-09	4.36E-09	4.77E-06	6.02E-08	2.22E-08	1.43E-10	4.45E-09
Standard deviation	8.29E-08	5.17E-08	1.46E-08	4.05E-08	1.69E-08	1.22E-09	1.83E-08	1.95E-08	2.13E-05	2.69E-07	9.91E-08	6.37E-10	1.99E-08
Minimum	1.77E-07	6.77E-08	1.77E-08	1.1E-07	5.99E-09	3.55E-10	5.79E-08	5.52E-08	7E-05	1.99E-06	2.97E-07	5.96E-11	1.77E-08
Maximum	5.09E-07	3E-07	6.04E-08	2.34E-07	7.15E-08	4.75E-09	1.34E-07	1.5E-07	0.000157	3.1E-06	7.79E-07	3.07E-09	9.99E-08

Table S12 Average Daily Exposure for Potential Non-carcinogenic Risk of trace elements in Soils of the Study Area through Ingestion Contact

Agriculture area	Li	Cr	Co	Ni	Mo	Cd	Pb	Cu	Fe	Mn	Zn	Se	As
Mean	8.54E-05	8.2E-05	1.44E-05	5.87E-05	8.93E-06	7.58E-07	3.91E-05	3.99E-05	0.040269	0.000873	0.000199	3.83E-07	1.99E-05
Standard error	4.97E-06	5.06E-06	7.44E-07	3.92E-06	1.63E-06	1.19E-07	2.61E-06	2.08E-06	0.001016	1.82E-05	4.35E-05	2.09E-08	9.82E-07
Standard deviation	2.44E-05	2.48E-05	3.64E-06	1.92E-05	7.99E-06	5.83E-07	1.28E-05	1.02E-05	0.004979	8.91E-05	0.000213	1.02E-07	4.81E-06
Minimum	5.35E-05	4.8E-05	9.74E-06	3.2E-05	1.24E-06	2.99E-07	2.47E-05	2.42E-05	0.02893	0.000716	8.65E-05	1.81E-07	1.29E-05
Maximum	0.000145	0.00013	2.16E-05	9.81E-05	3.43E-05	2.72E-06	7.15E-05	6.96E-05	0.048271	0.001043	0.00101	5.94E-07	3.05E-05
Pasture area	Li	Cr	Co	Ni	Mo	Cd	Pb	Cu	Fe	Mn	Zn	Se	As
Mean	8.94E-05	7.42E-05	1.3E-05	5.29E-05	6.29E-06	6.21E-07	2.94E-05	3.61E-05	0.041267	0.000861	0.000169	3.91E-07	2.1E-05
Standard error	6.09E-06	3.79E-06	1.07E-06	2.97E-06	1.24E-06	8.98E-08	1.35E-06	1.43E-06	0.001566	1.98E-05	7.28E-06	4.68E-08	1.46E-06
Standard deviation	2.72E-05	1.7E-05	4.8E-06	1.33E-05	5.56E-06	4.01E-07	6.02E-06	6.4E-06	0.007004	8.85E-05	3.26E-05	2.09E-07	6.54E-06
Minimum	5.82E-05	2.22E-05	5.81E-06	3.63E-05	1.97E-06	1.17E-07	1.9E-05	1.81E-05	0.022985	0.000655	9.76E-05	1.96E-08	5.83E-06
Maximum	0.000167	9.87E-05	1.98E-05	7.68E-05	2.35E-05	1.56E-06	4.39E-05	4.92E-05	0.051551	0.001017	0.000256	1.01E-06	3.28E-05

Table S13 Average Daily Exposure for Potential Non-carcinogenic Risk of Trace Elements in Soils of the Study Area through Inhalation

Agriculture area	Li	Cr	Co	Ni	Mo	Cd	Pb	Cu	Fe	Mn	Zn	Se	As
Mean	8.04E-09	7.71E-09	1.35E-09	5.53E-09	8.41E-10	7.13E-11	3.68E-09	3.75E-09	3.79E-06	8.22E-08	1.88E-08	3.61E-11	1.87E-09
Standard error	4.68E-10	4.76E-10	7E-11	3.69E-10	1.53E-10	1.12E-11	2.46E-10	1.96E-10	9.57E-08	1.71E-09	4.09E-09	1.97E-12	9.24E-11
Standard deviation	2.29E-09	2.33E-09	3.43E-10	1.81E-09	7.52E-10	5.49E-11	1.21E-09	9.6E-10	4.69E-07	8.38E-09	2.01E-08	9.65E-12	4.53E-10
Minimum	5.04E-09	4.52E-09	9.17E-10	3.01E-09	1.16E-10	2.81E-11	2.32E-09	2.28E-09	2.72E-06	6.74E-08	8.14E-09	1.7E-11	1.21E-09
Maximum	1.36E-08	1.22E-08	2.03E-09	9.24E-09	3.23E-09	2.56E-10	6.73E-09	6.55E-09	4.54E-06	9.82E-08	9.51E-08	5.59E-11	2.87E-09
Pasture area	Li	Cr	Co	Ni	Mo	Cd	Pb	Cu	Fe	Mn	Zn	Se	As
Mean	8.41E-09	6.98E-09	1.22E-09	4.97E-09	5.92E-10	5.84E-11	2.77E-09	3.4E-09	3.88E-06	8.1E-08	1.59E-08	3.68E-11	1.98E-09
Standard error	5.73E-10	3.57E-10	1.01E-10	2.8E-10	1.17E-10	8.45E-12	1.27E-10	1.35E-10	1.47E-07	1.86E-09	6.85E-10	4.41E-12	1.38E-10
Standard deviation	2.56E-09	1.6E-09	4.52E-10	1.25E-09	5.23E-10	3.78E-11	5.66E-10	6.03E-10	6.59E-07	8.32E-09	3.06E-09	1.97E-11	6.15E-10
Minimum	5.48E-09	2.09E-09	5.47E-10	3.41E-09	1.85E-10	1.1E-11	1.79E-09	1.71E-09	2.16E-06	6.16E-08	9.18E-09	1.84E-12	5.48E-10
Maximum	1.57E-08	9.29E-09	1.87E-09	7.23E-09	2.21E-09	1.47E-10	4.13E-09	4.63E-09	4.85E-06	9.58E-08	2.41E-08	9.5E-11	3.09E-09

Table S14 Evaluation of Potential Non-cancer Risk Assessment of Trace Elements in 0-5 cm Soils of the Study Area

Agriculture	ing_Mn	derm_Mn	inh_Mn	ing_Co	derm_Co	inh_Co	ing_Zn	derm_Zn	inh_Zn	ing_As	Cd_All	Cr_All	Cu_All	Ni_All	Pb_All
Mean	6.236E-03	9.494E-05	1.643E-03	4.784E-02	7.283E-04	2.251E-04	6.646E-04	1.012E-05	5.361E-07	6.633E-02	8.500E-04	3.073E-02	1.013E-03	3.163E-03	1.142E-0
Standard error	1.299E-04	1.977E-06	3.422E-05	2.480E-03	3.776E-05	1.167E-05	1.450E-04	2.207E-06	1.169E-07	3.272E-03	1.336E-04	1.896E-03	5.290E-05	2.109E-04	7.628E-0
Standard deviation	6.362E-04	9.686E-06	1.677E-04	1.215E-02	1.850E-04	5.717E-05	7.102E-04	1.081E-05	5.729E-07	1.603E-02	6.545E-04	9.291E-03	2.592E-04	1.033E-03	3.737E-0
Minmum	5.112E-03	7.782E-05	1.347E-03	3.247E-02	4.943E-04	1.528E-04	2.884E-04	4.390E-06	2.326E-07	4.303E-02	3.354E-04	1.799E-02	6.152E-04	1.722E-03	7.196E-0
Maxmum	7.453E-03	1.135E-04	1.964E-03	7.193E-02	1.095E-03	3.385E-04	3.368E-03	5.127E-05	2.717E-06	1.017E-01	3.048E-03	4.876E-02	1.767E-03	5.286E-03	2.085E-0
Pas	ing_Mn	derm_Mn	inh_Mn	ing_Co	derm_Co	inh_Co	ing_Zn	derm_Zn	inh_Zn	ing_As	Cd_All	Cr_All	Cu_All	Ni_All	Pb_All
Mean	6.148E-03	9.360E-05	1.620E-03	4.318E-02	6.575E-04	2.032E-04	5.635E-04	8.579E-06	4.546E-07	7.008E-02	6.962E-04	2.781E-02	9.175E-04	2.846E-03	8.584E-0
Standard error	1.413E-04	2.151E-06	3.723E-05	3.580E-03	5.450E-05	1.685E-05	2.427E-05	3.695E-07	1.958E-08	4.872E-03	1.007E-04	1.422E-03	3.638E-05	1.602E-04	3.924E-0
Standard deviation	6.318E-04	9.619E-06	1.665E-04	1.601E-02	2.437E-04	7.533E-05	1.085E-04	1.652E-06	8.755E-08	2.179E-02	4.504E-04	6.361E-03	1.627E-04	7.162E-04	1.755E-0
Minmum	4.677E-03	7.121E-05	1.233E-03	1.937E-02	2.949E-04	9.116E-05	3.253E-04	4.952E-06	2.624E-07	1.942E-02	1.308E-04	8.340E-03	4.607E-04	1.953E-03	5.550E-0
Maxmum	7.267E-03	1.106E-04	1.915E-03	6.611E-02	1.006E-03	3.111E-04	8.530E-04	1.299E-05	6.881E-07	1.094E-01	1.750E-03	3.699E-02	1.249E-03	4.135E-03	1.279E-0