Study on health risk assessment of potentially toxic elements in the soil around landfill site in Shannan City, Tibet

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ABSTRACT
This paper takes the soil around the Luqionggang landfill in Shannan city of Tibet Autonomous Region as the research object and studies the soil around the Luqionggang landfill by setting points and sampling. Then ICP-MS and AFS were used to analyze the contents of potentially toxic elements (PTEs) (Cu, Pb, Zn, Cr, Ni, Cd, As, Hg) in soil, and the health risk index method was used for risk assessment. The results showed that the primary exposure route of non-carcinogenic risk in the population was the oral route. And adults’ HI value is 0.1692, which is less than children’s HI value of 1.192, indicating that children are more affected than adults. Attention should be paid to the impact of PTEs As, Pb, and Cr in non-carcinogenic risk distribution. In the whole life cycle, the carcinogenic risk of the oral route is higher than that of the respiratory and skin contact routes.

Introduction

With the acceleration of urbanization and the prosperity of tourism in Tibet, municipal solid waste and tourism waste are increasing year by year [1]. From 2014 to 2018, the output of municipal solid waste in Tibet increased yearly, from 376,000 tons to 781,100 tons. The output of domestic waste is large, the types and components are complex, and the toxic and harmful substances in waste potentially harm the surrounding environment. Therefore, the effective treatment of waste has become one of the main social problems. Landfill, incineration, and composting are standard waste treatment technologies. Landfill and incineration are the main methods in China [2]. In Tibet, sanitary landfill is mainly used for waste treatment. In 2017, Lhasa established the first waste incineration power plant in Tibet [1]. The Sanitary landfill method has the advantages of simple technology, large treatment capacity, low cost, and is suitable for all waste. However, a certain amount of leachate will be produced in the landfill to pollute the surrounding soil, water, air, and other environments [3]. Among them, the main problems brought to the soil, such as heavy metal pollution, a sharp reduction of organisms, land degradation, ecological security, and landscape damage, also make the topsoil gradually becomes the source and sink of heavy metal pollution [4–8]. And soil heavy metal pollution is long-term, difficult to repair, concealment, and complex [9]. However, if the concentration of heavy metals in the soil exceeds the critical value, it will threaten the human body. And it’s necessary to keep the concentration of heavy metals at a low level in the environment [10]. Some heavy metals, even in low concentrations, will also have an impact on human health, such as causing children’s mental decline, damaging the nervous system, immune system, and internal organs [11–14]. Heavy metals are non-degradable, bioaccumulative, and biomagnificant in the food chain [15]. And entering the human body through dietary intake, respiratory intake, and skin contact will cause irreversible damage to human tissues [15–18].

Some scholars have studied the potentially toxic elements (PTEs) released into nature are mainly from human activities, such as domestic waste, agricultural, industrial, etc [11,19–21]. For the analysis of the impact of heavy metals and PTEs on Soil and water in the natural environment, the commonly used methods at present mainly include enrichment factor, geo-accumulation index, pollution load index, pollution index, potential ecological risk index, health risk index, pollution load index, Nemerow comprehensive pollution index, comprehensive pollution index, etc [20–24]. In addition, some statistical methods, such as correlation analysis, principal component analysis, factor analysis, and cluster analysis, are often used in the study of the relationship between pollutants (such as heavy metals, PTEs) in soil and surface water, groundwater, human activities [20,21]. In addition, some scholars have reported the word heavy metals and PTEs in the literature, suggesting the use of PTEs [25–27].

Shannan City, Tibet, uses a sanitary landfill to treat municipal solid waste. Luqionggang landfill site locates in Zedang town at the junction of Naidong district and
Sangri County, Shannan city. It is the only sanitary landfill in the urban area of Shannan city and is representative. Therefore, this study takes the soil around the Luqionggang landfill as the research object for the first time. The surrounding soil's concentrations of 8 kinds of PTEs (Cu, Pb, Zn, Cd, Cr, Ni, As, and Hg) were investigated, and the health risk was evaluated. It provides reference suggestions for preventing and controlling soil pollution at the Shannan landfill site.

1. Experimental part

1.1 Overview of the landfill site

Luqionggang domestic waste landfill locates in Zedang Town, Naidong District, Shannan City, within latitude 29°15′07′′N and longitude 91°50′41′′E (Figure 1), with an average altitude of 3700 meters. This area belongs to the temperate arid climate zone under plateau conditions, and the annual average precipitation is less than 450 ml. The landfill site is surrounded by mountains on three sides, at the foot of the mountain, and there is no human habitation around it. Luqionggang landfill site was constructed on 30 October 2002, covering an area of 8.53 hectares. The designed landfill capacity is 600,000 tons, about 400,000 cubic meters, and the design service life is 20 years. The landfill was put into use in May 2007, with a landfill volume of more than 370,000 tons. The landfill site is planned to be divided into four landfill areas. Each landfill area divide into three layers, and each layer is about 3 m high. In addition, gas guiding equipment is set in the landfill area, and a particular percolation collection network is laid at the bottom of the landfill area. The flood intercepting ditch is built on the hillside around the landfill to prevent rainwater from entering the site. Moreover, with the increase in the service life of the landfill, more problems emerge, the rise in the treatment load, the aging of the equipment, the reduction of the service life, and the lack of waste metering equipment, etc.

1.2 Sample collection

The sampling points are designed according to the landfill site’s topography and the mountains’ characteristics on three sides. Firstly, the terrain and surface layer with a particular slope in the landfill’s north, East, and south directions are primarily rocks, so the soil sample points are set as three groups of sampling points in each direction. The sampling points are 10 m and 20 m away from the landfill site, and the interval between each group is 100 m. Therefore, there are 18 sampling points in these three directions, numbered according to the direction. The west side of the landfill site is relatively flat, so sampling points are set 10 m, 50 m, 100 m, and 300 m away from the landfill site. A total of 5 groups of sampling points are set, with an interval of 100 m between each group. It is learned

Figure 1. Location map of soil sampling points in landfill.
from the site that the soil layer in the west of the landfill site is thick, so each sample point is also sampled according to different depth layers, which are 0–5 cm, 10–15 cm, 20–25 cm, and 30–35 cm respectively. Therefore, 80 samples were sampled in the west of the landfill and numbered in different directions. Then, two soil samples were taken in the hills on the east side of the landfill as control samples. In the sampling process, each sampling point is sampled by the plum blossom method, and the GPS point is marked simultaneously. The specific layout of sampling points in the landfill is shown in Figure 1.

1.3 Data sources

Heavy metals penetrate the soil layer in various ways and stay in the soil layer, which further affects crops and human health, making it difficult to repair the soil quality. Therefore, the analysis of the concentration of heavy metals can understand the relationship between heavy metals in soil and surface water, groundwater, and human activities [28]. Heavy metals in environmental pollution refer to metals or metalloids such as Hg, Cd, Pb, Cr, and As, and generally toxic metals such as Cu, Zn, Ni, Co, Sn, and so on [29]. Therefore, the eight PTEs Cu, Pb, Zn, Cd, Cr, Ni, As, and Hg in the soil environmental quality standard that causes specific harm to farmland and groundwater are used as the monitoring objects of heavy metals in the study. Modern instruments are also used to evaluate and analyze heavy metals, such as ANN, PCA, FA, HCA, LRA, MLR, etc [30,31]. However, the content of PTEs Cu, Pb, Zn, Cd, Cr, and Ni in this study was determined by the soil and sediment-determination of aqua regia extracts of 12 metal elements inductively coupled plasma mass spectrometry (HJ803-2016), mainly using coupled plasma. ICP-MS used in the analysis is a NexION 300 inductively coupled plasma mass spectrometer produced by PerkinElmer. The content of PTEs As and Hg is determined by the analysis methods for Regional Geochemical Sample-Part 13(DZ/T0279.13–2016), mainly by atomic fluorescence spectrometry. AFS used in the analysis is the AFS-820 atomic fluorescence spectrometer produced by the Beijing Jitian company.

1.4 Health risk index method

1.4.1 Exposure model and parameters

The United States Environmental Protection Agency (USEPA) has put forward a calculation model of exposure. Then, according to the exposure routes of soil health risk assessment mentioned in the technical guidelines for risk assessment of soil contamination of land for construction, the oral route, skin route, and respiratory route are mainly adopted. These three ways’ exposure calculation model formulas refer to technical guidelines and references [32–37]. The formula is as follows:1–6.

Daily average exposure by oral route (CDI_{ing}):

$$CDI_{ing} = \frac{C \times InhR \times EF \times ED \times CF}{BW \times AT}$$ (1)

Average daily exposure throughout the life cycle:

$$LADD = \frac{C \times EF \times CF}{AT} \times \left( \frac{InhR_{child} \times ED_{child}}{BW_{child}} + \frac{InhR_{adult} \times ED_{adult}}{BW_{adult}} \right)$$ (2)

Daily average exposure through respiratory inhalation (CDI_{inh}):

$$CDI_{inh} = \frac{C \times InhR \times EF \times ED}{BW \times AT \times PEF}$$ (3)

Average daily exposure throughout the life cycle:

$$LADD = \frac{C \times EF}{PEF \times AT} \times \left( \frac{InhR_{child} \times ED_{child}}{BW_{child}} + \frac{InhR_{adult} \times ED_{adult}}{BW_{adult}} \right)$$ (4)

Daily average exposure through skin contact (CDI_{der}):

$$CDI_{der} = \frac{C \times SA \times SL \times ABS \times EF \times ED \times CF}{BW \times AT}$$ (5)

Average daily exposure throughout the life cycle:

$$LADD = \frac{C \times EF \times CF}{AT} \times \left( \frac{CR_{child} \times ED_{child}}{BW_{child}} + \frac{CR_{adult} \times ED_{adult}}{BW_{adult}} \right)$$ (6)

The relevant parameters in the formula are listed according to the Technical guidelines for risk assessment of contaminated sites in the People’s Republic of China and relevant literature [35,38,39], such as Table 1. Among them, EF is the exposure frequency, and EF in the whole life cycle calculation is 365. BW is the average body weight, of which the average body weight of adults is 62 kg [39]. AT is the average action time, which is the product of life expectancy and 365 days, while the average life expectancy in Tibet is 68.2 [39]. SA is the exposed area of the skin that may be contacted. And considering that the clothing in the plateau area is mainly warm and the exposed area of the body is less, the SA skin exposure area in the study of Li et al. [35] is adopted. LADD is the average exposure on the last birthday. A8S is a skin absorption factor. CR is the skin contact strength, and its value is calculated as follows::

$$CR = SA \times SL \times ABS$$ (7)

1.4.2 Health risk characterization

Non-carcinogenic risk index refers to the non-carcinogenic risk generated by the exposure route of
pollutants, which is usually the ratio of the exposure amount of contaminants to the reference dose. The formula is as follows:

$$HQ = \frac{CDI}{Rfd}$$  \hspace{1cm} (8)

Total non-carcinogenic risk, and its value is calculated as follows:

$$HI = \sum_{i=1}^{m} \sum_{j=1}^{n} HQ_{ij} = \sum_{i=1}^{m} \sum_{j=1}^{n} \left( \frac{CDI}{Rfd} \right)_{ij}$$  \hspace{1cm} (9)

HQ is the Non-carcinogenic risk index. HI is the entire non-carcinogenic risk. CDI is the average daily exposure dose of the human body. Rfd is a non-carcinogenic reference dose. M is the type of pollutants, and N is the number of exposure routes. If the value of HQ and HI is greater than 1, it indicates a high non-carcinogenic risk here. If it is less than 1, there is a small non-carcinogenic risk here [34].

Carcinogenic risk is the product of average exposure at the end of life and the carcinogenic slope factor [35]. The formula is as follows:

$$R = LADD \times SF$$  \hspace{1cm} (10)

Total cancer risk is as follows:

$$R = \sum_{i=1}^{m} \sum_{j=1}^{n} R_{ij} = \sum_{i=1}^{m} \sum_{j=1}^{n} (LADD \cdot SF)_{ij}$$  \hspace{1cm} (11)

R is the Carcinogenic risk. LADD is the average exposure on the last birthday. SF is the carcinogenic slope factor [5]. According to the reference dose and carcinogenic slope factor in the international agency for research on cancer (IARC), the World Health Organization (WHO), and relevant literature [32,33,35,40–45], the reference dose and slope factor of the elements selected in this study are shown in Table 2.

2 Results and discussion

2.1 Test results of PTEs in the soil around the landfill site

The pH value of soil samples around the landfill site was monitored. The results show that the average pH value of the soil around the landfill is 9.37, which is strongly alkaline [21]. In the study of soil fertility of croplands in major agricultural areas in Tibet, the results show that the soil in Shannan city is alkaline (pH 8.3–8.7) [46], which may be due to the influence of soil parent material and climate change on the altitude of Tibet [39]. The monitoring and analysis results of PTEs content in the soil of Luqiongang landfill in Shannan city are shown in Table 3 and Figure 2. Figure 2 shows that the average content of PTEs in landfills is Zn > Cr > Ni > Pb > Cu > As > Cd > Hg. It can be seen that the coefficient of variation is between 0.15 and 2.75, and the PTEs Pb, Cr, and As belong to low variation. PTEs Cu, Zn, Ni, and Cd belong to medium variation. The variation of PTEs Hg is extreme, which indicates that the spatial distribution of PTEs Hg in the study area is different, and the content difference between sampling points is huge [21]. Zhang et al. [47] also showed that Hg and As had large coefficients of variation and were greatly affected by human activities. In addition, only one sample point of Cu in PTEs exceeded the risk screening value of the national soil environmental quality standard (GB 15618–2018). And there were 16 samples of PTEs As exceeding the risk screening value, which shows the accumulation of PTEs As in the soil around the landfill site to a certain extent. The high value of PTEs As will produce potential risks to the surrounding soil environment, and the urgency of taking protective measures for the surrounding soil environment is obvious. However, according to the analysis of the background value of the soil environment in Tibet, the contents of the eight PTEs all exceeded the background value of soil in Tibet. Among them, exceeding the standard ranged from 9.18% to 88.78%. The proportion of As element exceeding the background value is the highest, which is 88.78% [21].

2.2 Exposure dose calculation results

Each population's daily exposure dose of different exposure routes is calculated using the average value of pollutants, and the results are shown in Table 4. Overall, the order of different PTEs under different exposure routes is the oral intake, skin

| Table 1. Parameter name, unit, symbol, and reference value. |
|-------------------------------------------------------------|
| Parameter name/Unit                                        | Symbol | Reference value |
| Content of PTEs in soil/(mg/kg)                             |        |                |
| Oral intake rate/                                         |        |                |
| (mg·d⁻¹⁻) Adult                                           | IngR   | 100            |
| Child                                                     |        | 200            |
| Respiratory                                              |        |                |
| (m³·d⁻¹) Adult                                           | InhR   | 12.8           |
| Child                                                     |        | 7.63           |
| Exposure frequency/                                       |        |                |
| (d⁻¹) Adult                                               | EF     | 350            |
| Child                                                     |        | 320            |
| Exposure delay/                                           |        |                |
| (a⁻¹) Adult                                               | ED     | 365            |
| Child                                                     |        | 24             |
| Weight/kg                                                |        |                |
| Adult                                                     | BW     | 62             |
| Child                                                     |        | 15.9           |
| Average exposure                                         |        |                |
| exposure time/d                                          |        |                |
| Carcinogenic risk/Adult                                   | AT     | 68.2365 = 24,893 |
| Child                                                     |        | 2190           |
| Body surface area/cm²                                     |        |                |
| Adult                                                     | SA     | 2145           |
| Child                                                     |        | 1150           |
| Skin adhesion coefficient/                                |        |                |
| (mg.(cm⁻²).d⁻¹⁻) Adult                                   | SL     | 0.07           |
| Child                                                     |        | 0.2            |
| Skin absorption factor                                    |        |                |
| Others                                                    | ABS    | 0.03           |
| Particulate emission factor                               |        |                |
| Others                                                    | PEF    | 1.36×10⁹      |
| Average exposure at the end of life cycle/ LADD           |        |                |
| (mg.(kg.d⁻¹⁻))                                           |        |                |
| Conversion coefficient                                    | CF     | 1×10⁻⁶        |
intake, and respiratory pathway, which indicates that oral exposure is the primary exposure route of human exposure to pollutants. Among them, the exposure dose of PTEs Zn is the highest, related to the high content of PTEs Zn in soil PTEs detection. Under the three routes of exposure, the exposure dose of children is generally higher than that of adults. It may be since children’s weight and skin surface area are lower than adults, resulting in higher exposure doses in the evaluation than adults [48]. Through the calculation results of exposure dose, we can understand the impact of PTEs on the human body, in which children will be more affected than adults.
2.3 Health risk assessment results

2.3.1 Non-carcinogenic risk
The total non-carcinogenic risks of PTEs to adults and children under different exposure routes are shown in Table 5. The data in Table 5 shows that the entire non-carcinogenic risk of a single PTEs in all groups is less than 1. The non-carcinogenic risk value of the adult oral route was $1.611 \times 10^{-1}$ which accounts for 95.21% of the total non-carcinogenic risk. The non-carcinogenic risk value caused by skin contact and the respiratory route was $7.628 \times 10^{-3}$ and $3.293 \times 10^{-4}$. However, the non-carcinogenic risk value of children under the oral route is 1.149, accounting for 96.39% of the total non-carcinogenic risk. Its non-carcinogenic risk value is greater than 1, indicating a high non-carcinogenic risk. The non-carcinogenic risk values under the skin contact and respiratory routes were $4.165 \times 10^{-2}$ and $6.532 \times 10^{-3}$. It can be seen that the oral route is the primary exposure route to non-carcinogenic risk. In addition, the data in Table 5 shows that the total risk value of non-carcinogenic is 0.1692 for adults and 1.192 for children, which indicates that PTEs pollution in the soil around the landfill site has an apparent non-carcinogenic risk to children. Research shows that PTEs with HQ greater than 1 are the most effective, which also indicates that PTEs are the most effective on children [1,11,12,24,49]. Studies have shown that children’s physiological development is incomplete, and they are more sensitive to the toxicity of PTEs. And their long-term exposure to the polluted environment may result in higher non-carcinogenic risk [50,51]. For the adult population, the total risk of non-carcinogenesis mainly comes from the PTEs Pb, Cr, and As, and the contribution of As reaches 69.14%. The entire non-carcinogenic risk for children comes from PTEs Pb, Cr, Ni, and As, of which Cr and As account for 89.63% of the total risk, indicating the need to pay attention to the monitoring of PTEs As. The proportion of the non-carcinogenic risk of these eight PTEs under different exposure routes is different, and the non-carcinogenic risk caused by the main oral route is higher. However, we should not ignore the non-carcinogenic risk caused by PTEs Cr and As through skin contact.

2.3.2 Carcinogenic risk
The carcinogenic risk of the whole life cycle is calculated according to the relevant carcinogenic slope factors in Table 2, and the results are shown in Table 6. USEPA’s maximum acceptable risk level is $1 \times 10^{-6}$, and the negligible risk level is $1 \times 10^{-10}$. In the study of some others, the health risk of Chinese people is divided into four groups: high risk ($10^{-2}$), medium risk ($10^{-4}$-$10^{-5}$), medium & low risk ($10^{-6}$-$10^{-9}$), low risk ($10^{-9}$) [52]. It can be seen from Table 6 that the carcinogenic risk values of all PTEs are lower than the maximum acceptable level of $1 \times 10^{-4}$. In the whole life cycle, the highest carcinogenic risk of the oral route is $5.497 \times 10^{-5}$. The risk of carcinogenesis caused by respiratory route and skin contact is $3.361 \times 10^{-6}$ and $2.172 \times 10^{-6}$. Compared with different routes, the main carcinogenic risk of oral and skin contact routes is PTEs.
As. The maximum acceptable level of oral and skin contact routes was $5.452 \times 10^{-5}$ and $2.076 \times 10^{-6}$; they all belong to medium and low risk. The PTEs with a high risk of carcinogenesis under the respiratory pathway is Cr, and the maximum acceptable level is $3.222 \times 10^{-6}$, which is medium and low risk. Compared with a single PTEs, the maximum carcinogenic risk value in the whole life cycle is As, followed by PTEs Cr and Cd. The carcinogenic risk value of these three PTEs is $5.669 \times 10^{-5}$, $3.222 \times 10^{-6}$ and $1.021 \times 10^{-6}$, all of which are medium and low-level risks. The data relating to PTEs also shows that the region needs to pay attention to the impact of PTEs As.

### 3. Conclusion

Among the 98 samples collected from the soil around the landfill site, the non-carcinogenic risk values of eight PTEs Cu, Pb, Zn, Cr, Ni, Cd, As, and Hg are within the acceptable level. The PTEs that contribute to non-carcinogenic risk in different groups are Pb, Cr, Ni, and As elements. In adults and children, the primary exposure route of non-carcinogenic risk is the oral route, and the exposure route of PTEs As and Cr through the skin in different groups should not be ignored. In the whole life cycle, the carcinogenic risk caused by the oral route is the highest, followed by the respiratory and skin contact routes. The PTEs have an impact on the carcinogenic risk of the oral route and skin contact route. The PTEs that impact the risk of carcinogenesis under the respiratory pathway is Cr. Compared with a single PTEs, the PTEs with the most considerable carcinogenic risk value in the whole life cycle is As, followed by PTEs Cr and Cd. The carcinogenic risk values of all PTEs were lower than the maximum acceptable level of $1 \times 10^{-6}$, ranging from $4.017 \times 10^{-6}$ to $5.669 \times 10^{-5}$.

### Disclosure statement

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### Data availability

All relevant data are within the manuscript and available from the corresponding author upon request.

### Ethical approval

This paper mainly studies the heavy metals in landfill soil, not involving human and animal research.

### Consent to participate

All authors were participated in this work.

### Consent to publish

All authors agree to publish.

### Author contributions

Zeng Dan and Guanyi Chen provided the research ideas and experimental equipment. Wenwu Zhou, Dean Meng, Peng Zhou completed the experimental operation and the arrangement and processing of experimental data.

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### Table 6. Carcinogenic risk of PTEs in different exposure routes.

| PTEs | $R_{or}$ | $R_{in}$ | $R_{dermal}$ | $R_{total}$ |
|------|----------|----------|--------------|-------------|
| Pb   | $3.921 \times 10^{-7}$ | $3.222 \times 10^{-6}$ | -- | $3.921 \times 10^{-7}$ |
| Cr   | --       | $4.017 \times 10^{-8}$ | -- | $4.017 \times 10^{-8}$ |
| Ni   | --       | $7.060 \times 10^{-10}$ | $9.602 \times 10^{-8}$ | $1.021 \times 10^{-6}$ |
| Cd   | $5.982 \times 10^{-6}$ | $9.781 \times 10^{-8}$ | $2.076 \times 10^{-6}$ | $5.669 \times 10^{-5}$ |
| As   | $5.452 \times 10^{-5}$ | $3.361 \times 10^{-6}$ | $2.172 \times 10^{-6}$ | $6.137 \times 10^{-5}$ |
| Total| $5.497 \times 10^{-3}$ | $3.361 \times 10^{-6}$ | $2.172 \times 10^{-6}$ | $6.137 \times 10^{-5}$ |
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