



Distribution characteristics and potential ecological risk assessment of heavy metals in soils around Shannan landfill site, Tibet

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Abstract At present, sanitary landfill is mainly used for domestic waste treatment in Shannan City, Tibet. However, there are few studies on heavy metals in the soil around the landfill in Shannan city. Therefore, the surrounding soil of Luqionggang landfill in Shannan City, Tibet Autonomous Region, is taken as the research object. In the study, the geo-accumulation index method, Nemerow comprehensive pollution index method and potential ecological risk index method are mainly used to evaluate the pollution and risk of heavy metals in the soil around the landfill site. The main results are as follows: The average pH value of the soil around the landfill site is 9.37, belonging to the strong alkaline range. The average values of heavy metals Hg and Ni in soil exceeded the background content, and the average contents of other heavy metals Cu, Pb, Zn, Cr, As and Cd did not exceed the background content. The average content of these eight heavy metals did not exceed the screening value of the national soil environmental quality standard. In the horizontal

direction, the average content of heavy metal elements Cu, Cr, Cd, Hg and Ni is relatively high in the west. The average content of heavy metals As, Zn and Pb in the north, east and south is slightly higher than that in the west. And the farther away from the landfill, the less the soil is affected by heavy metals. The evaluation results of geo-accumulation index show that heavy metal Hg is the most affected. The average value of the comprehensive pollution index is 2.969, which is between 2 and 3, belonging to the moderate pollution level. And the west side of the landfill (downstream area) is greatly affected. The evaluation results of potential ecological hazard pollution index show that the potential risk index of single pollutants of heavy metals Cu, Pb, Zn, Cr, Ni, As and Cd belongs to low ecological hazard level, and the potential risk index of single pollutants of heavy metal Hg belongs to relatively heavy ecological hazard level. On the whole, the total potential risk coefficient belongs to medium pollution hazard degree. According to the correlation analysis, there is no significant correlation between heavy metal elements As and Hg and the other six heavy metal elements. In addition, the pollution source of heavy metal As may be mainly soil forming factors and the pollution source of Hg may be mainly human factors.

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Introduction

With the development of Tibet's economy, the acceleration of urbanization and the prosperity of tourism, domestic waste and tourism waste have increased year by year (Zhou et al., 2019). However, the output, types and components of domestic waste are complex, and the toxic and harmful substances in the garbage affect the surrounding water (Licht et al., 2005), soil (Booth et al., 1990; Chai et al., 2010), atmosphere (Pawlowska et al., 2000; Raskin et al., 1994) and ecosystem (Alejandro et al., 2008; Ding et al., 2007), and bring potential hazards to residents (Minichilli et al., 2005; Bakare et al., 2006; Jarup et al., 2002; Geschwind et al., 1992; Vrijheid et al., 2002; Elliott et al., 2001). At present, landfill, incineration and composting are the most common treatment technologies. In Tibet, the sanitary landfill is mainly used for domestic waste treatment (Dan et al., 2021; Zhou et al., 2020a; Zhou et al., 2020b), which has the advantages of simple operation and management, large treatment capacity, low investment and operation cost, and is suitable for all wastes (Ludvigsen et al., 1998; Berkun et al., 2005). However, landfill treatment mainly brings heavy metal pollution, land degradation, sharp reduction of biodiversity, landscape damage and ecological security (Allen, 2001; Dorothy et al., 2001; Kaschl et al., 2002; Adelopo et al., 2018; Booth et al., 1990; Shimbo et al., 2001). The heavy metals will also stay in the soil layer, and the pollution is long-term, difficult to repair, hidden and complex, which will affect the quality and safety of surrounding soil environment (Allen, 2001; Dorothy et al., 2001; Kaschl et al., 2002; Adelopo et al., 2018). The pollution of landfill to the surrounding soil is mainly related to the distance from the landfill site, the depth of soil layer, the length of landfill time, the amount of landfill and the composition of domestic waste, season, wind direction and other factors (Zhou, 2020). However, most of the domestic researches on soil heavy metals mainly focus on the spatial distribution characteristics, enrichment characteristics and potential ecological risks of soil heavy metals in mining areas, landfill sites, incineration plants, sewage irrigation areas, farmland, lakes and rivers in developed areas. However, there are few studies on the spatial distribution and potential ecological risks of landfills in plateau areas (Yuan et al., 2014; Fan et al., 2016; Wang et al., 2018a; Wang

et al., 2018b; Jiang et al., 2018; Yao et al., 2016; Yu et al., 2019; Tang et al., 2019; Jing et al., 2020; Wu et al., 2018b). Due to the toxicity of some heavy metals in the soil, they accumulate in plants and animals, so the pollution of heavy metals in soil has become a global problem (Yan et al., 2013; Wang et al., 2013). Therefore, timely understanding and improving the status of soil heavy metal pollution, improve the urban environment, has become an important issue of our concern.

Luqionggang landfill site in Zedang town is the only sanitary landfill site in Shannan City, which is very representative in Shannan city. At present, there is a lack of analysis and research on heavy metal pollution and evaluation of soil around Luqionggang landfill site. Therefore, for the first time, the surrounding area of Luqionggang landfill site is taken as the research object and the heavy metals in the surrounding soil are analyzed. The results of the evaluation provide reference suggestions for the soil pollution and prevention of Shannan municipal landfill and the plateau landfill.

Materials and methods

General situation of landfill

Luqionggang landfill is located in Zedang Town, Naidong District, Shannan City, bordering on Sangri county. Luqionggang landfill site belongs to valley type, and the north, east and south directions of the landfill are hilly areas. The terrain on the west side of the landfill site is relatively flat. The trend of the landfill site is inclined from east to west, and the west side is the downstream area of the landfill site. The construction of Luqionggang municipal solid waste landfill was started on October 30, 2002. The landfill area covers an area of 44000 hectares, and the design service life is 20 years. The landfill site was officially put into operation in May 2007, with a landfill capacity of more than 370000 tons so far. In 2007–2011, the actual daily treatment capacity of the landfill site was 120 tons/day. In 2012–2015, the actual daily treatment capacity of the landfill site reached 135 tons/day. In addition, there are gas guiding equipment in the landfill area, and a special seepage collection network is laid at the bottom of the landfill area. A

flood interception ditch is set on the hillside around the landfill site to prevent rainwater from entering the landfill area.

Soil sample collection and analysis

According to the terrain characteristics of the landfill site, in order to better investigate the soil heavy metal pollution around the landfill site. Therefore, different sampling points are arranged in each direction of the landfill site. Because the landfill is located at the foot of the mountain, and the landfill site has a certain slope in the north, east and south. The sampling points in these three directions are set at 10 and 20m away from the landfill site. Three groups of sampling points are set in each direction, and the interval between each group is 100m. Therefore, there are 18 sampling points in the three directions. The sampling points in the west of the landfill site are set at 10, 50, 100 and 300m away from the landfill site. Five

groups of sampling points are set up with an interval of 100m. In addition, each group of sampling points in the west of the landfill site is also set according to different soil depth. The depth of each sampling point is 0–5, 10–15, 20–25, 30–35cm. Therefore, a total of 80 samples were collected in the west of the landfill. The collected soil is the topsoil around the landfill site. During the process of depth sampling, it is found that the soil below 10cm contains a large number of stones. Each sampling point adopts plum blossom method to collect soil, and GPS positioning is carried out for each sampling point. Therefore, a total of 98 soil samples around the landfill were collected. The specific sampling point layout of the landfill site is shown in Fig. 1.

The contents of Cd, Cr, Cu, Ni, Pb, Zn, As and Hg in soil were determined. The contents of Cd, Cr, Cu, Ni, Pb and Zn were determined by the method mentioned in “Determination of 12 metal elements in soil and sediment by aqua regia extraction inductively

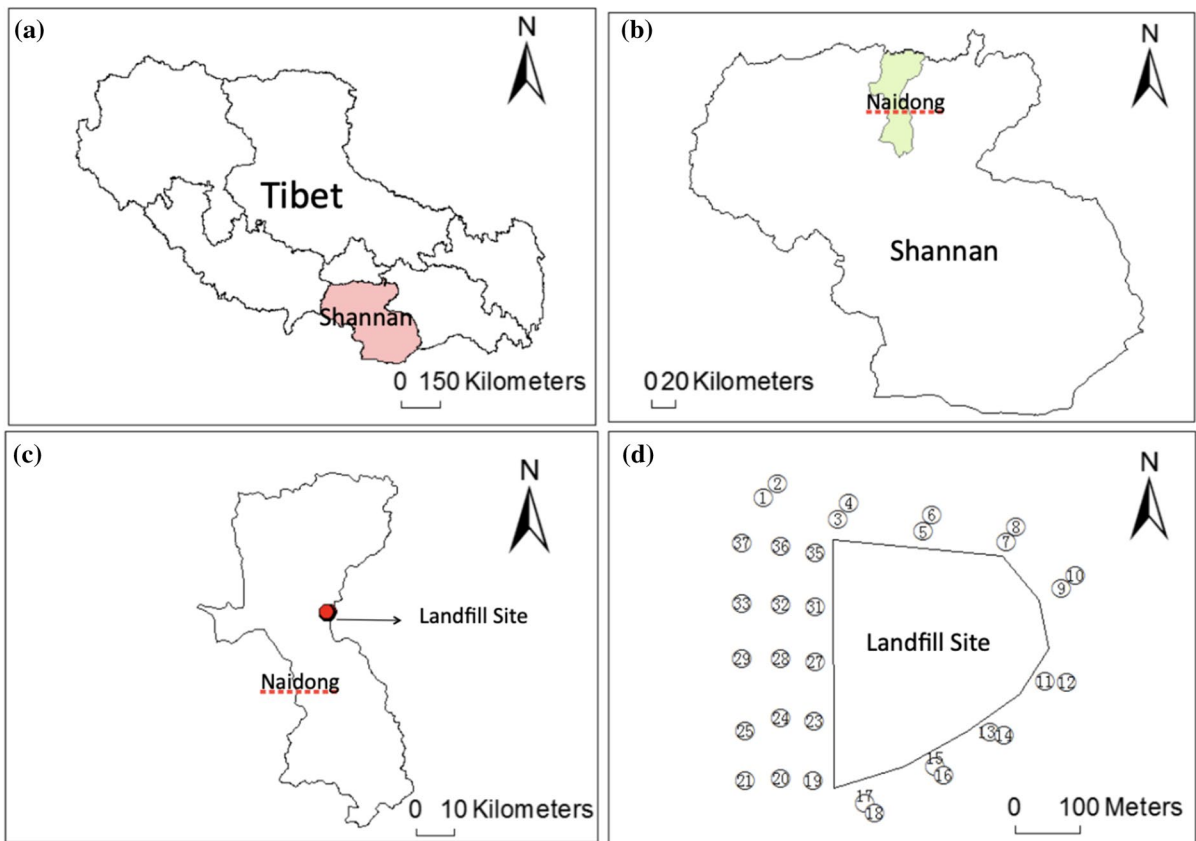


Fig. 1 Satellite map and soil sampling point map of landfill

coupled plasma mass spectrometry” (HJ803-2016). Inductively coupled plasma is mainly used in this method. This method comes from the national environmental protection standard of the People’s Republic of China. The contents of As and Hg are determined by the method mentioned in the regional geochemical sample analysis method (DZ/T0279-2016). Atomic fluorescence spectrometry is the main method. This method comes from the geological and mineral industry standard of the People’s Republic of China.

Evaluation method

Geo-accumulation index method

Geo-accumulation index was first used by German scientist Muller to study heavy metal pollution in aquatic sediments (Muller, 1969). This method mainly considers human factors and soil physical and chemical properties. The results show that human activities have an impact on the process of soil heavy metal pollution and the distribution of heavy metal elements in soil under natural conditions. In addition, this method also pays attention to the factors of background value change caused by natural diagenesis (Xu et al., 2019; Zhang et al., 2009; Christophoridis et al., 2009; Cevik et al., 2008), as shown in Eq. (1):

$$I_{geo} = \log_2 [C_n / (1.5 * B_n)] \quad (1)$$

where I_{geo} indicates the Geo-accumulation index; C_n indicates the concentration of element n in soil; 1.5 indicates the correction index; B_n indicates the background value of soil element n. This background value is the background value of soil in Tibet (Zhang, 1994). The degree of pollution is from no pollution to very strong pollution, and the classification is shown in Table S1.

Nemerow pollution index method

Nemerow pollution index method uses the average and maximum value of single pollution index and then comprehensively analyzes the degree of soil pollution (Zhou et al., 2020c; Nemerow, 1974; Remedios et al., 2019). This method can fully reflect the different degrees of soil pollution caused by various pollutants. It also highlights the impact of high

concentration on soil environmental quality, reflecting the comprehensive pollution level (Liu et al., 2013), as shown in Eq. (2):

$$P_N = \sqrt{\frac{\bar{S}_i^2 + S_{i_{max}}^2}{2}} \quad (2)$$

where PN indicates the comprehensive score value; S_i indicates the single index value; \bar{S}_i^2 indicates the average; $S_{i_{max}}^2$ indicates the maximum value. The classification standard of Nemerow comprehensive pollution index is shown in Table S2.

Potential ecological risk index

Hakanson established the potential ecological risk index method in 1980, which is mainly used for sedimentological assessment of heavy metal pollution and ecological hazards (Hakanson, 1980). The content of heavy metals in soil, ecological effect, environmental effect and toxicology of heavy metals were considered simultaneously in this method, and the comparable and equivalent attribute index grading method was used for evaluation (Yu et al., 2019; Hakanson, 1980; Lin et al., 2019; Wu et al., 2018a), as shown in Eq. (3):

$$RI = \sum_{i=1}^n E_r^i = \sum_{i=1}^n T_r^i \times C_f^i = \sum_{i=1}^n T_r^i \times \frac{C_n^i}{C_r^i} \quad (3)$$

RI indicates the potential ecological risk index of polymetallic; E_r^i indicates the potential risk index of single metal; T_r^i indicates the metal toxicity factor (Fan et al., 2016; Yu et al., 2019; Zhang et al., 2015b), shown in Table S3; C_f^i indicates the pollution coefficient of single metal; C_n^i indicates the measured concentration value; C_r^i indicates the background value of soil in Tibet (Zhang, 1994). The potential ecological risk index grading standard in Table S4 was used for analysis.

Source apportionment

In order to understand the correlation between the eight heavy metals and the sources of heavy metals, SPSS17.0 was used for correlation analysis and principal component analysis. According to the size of the correlation coefficient between the elements to

judge the correlation between the two, speculate its source (Huang et al., 2018; Zhang et al., 2018; Cai et al., 2015; Liang et al., 2019). In addition, principal component analysis is usually used to analyze the pollution sources of elements (Fang et al., 2019; Wang et al., 2020).

Spatial characteristic analysis method

Spatial distribution is an effective method to identify the source of pollutants and high pollution areas (Xiao et al., 2015). The spatial distribution characteristics of soil pollution were visualized by using the ordinary Kriging interpolation method in geo-statistics (Dai et al., 2019; Jin et al., 2019). ArcGIS 10.0 software is used in the drawing.

Result and discussion

Characteristics of heavy metal content in soil

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. 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) (Zhong et al., 2005), which may be due to the influence of soil parent material and climate change on the altitude of Tibet. The monitoring and analysis results of heavy metal content in soil of Luqionggang landfill in Shannan city are shown in Table S5. The average content of heavy metals in landfills is Zn > Cr > Ni > Pb > Cu > As > Cd > Hg. The dispersion degree of heavy metal elements in landfills is understood by coefficient of variation, in which the coefficient of variation is less than 0.2, belonging to low variation; 0.2–0.5, belonging to medium variation; 0.5–1, belonging to high variation; coefficient of variation is greater than 1, belonging to very strong variation (Karimi et al., 2015). Research shows that heavy metals are highly variable and vulnerable to human activities (Lv et al., 2019a). It can be seen that the coefficient of variation is between 0.15 and 2.75, and the heavy metals Pb, Cr and As belong to low variation. Heavy metals Cu, Zn, Ni and Cd belong to medium variation. The variation of heavy metal Hg is very strong, which indicates that the spatial

distribution of heavy metal Hg in the study area is different, and the content difference between sampling points is very large. Zhang et al. (2015a) also showed that Hg and As had large coefficients of variation and were greatly affected by human activities. In addition, only one point of Cu in heavy metals exceeded the risk screening value of national soil environmental quality standard (GB 15618-2018). There were 16 samples of heavy metal As exceeding the risk screening value. However, according to the analysis of the background value of soil environment in Tibet, the contents of the eight heavy metals all exceeded the background value of soil in Tibet. Among them, the proportion of 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%. Therefore, Tibet soil background value is used in the evaluation process of geo-accumulation index method and potential ecological risk index method.

Distribution characteristics of heavy metals in soil

Horizontal distribution characteristics

GIS was used to map and analyze the spatial distribution of heavy metals in the soil around the landfill site, as shown in Fig. 2. The west side of the landfill is sampled according to the depth of the soil layer, so the average value is used in the drawing. The closer to the landfill, the concentration of heavy metals in the soil is the higher than in others area. Some scholars are studying Chengdu landfill in China, the closer to the landfill, the higher the content of heavy metals (Tu et al., 2013; Zhang et al., 2015c). Some scholars also showed that the concentration of heavy metals in landfill soil decreased from the center to the edge (Wang et al., 2020). It can also be seen from the figure that the west side of the landfill is mainly the downstream area of the landfill, and the concentration of heavy metals is higher than that in the east, north and south of the landfill. This is because the landfills are inclined from east to west, resulting in the high content of heavy metals in the west. It could be seen from the figure that the content of heavy metals As in the west of the landfill site is less than that in the north, east and south. According to the observation of field sampling, the soil on the west side of the

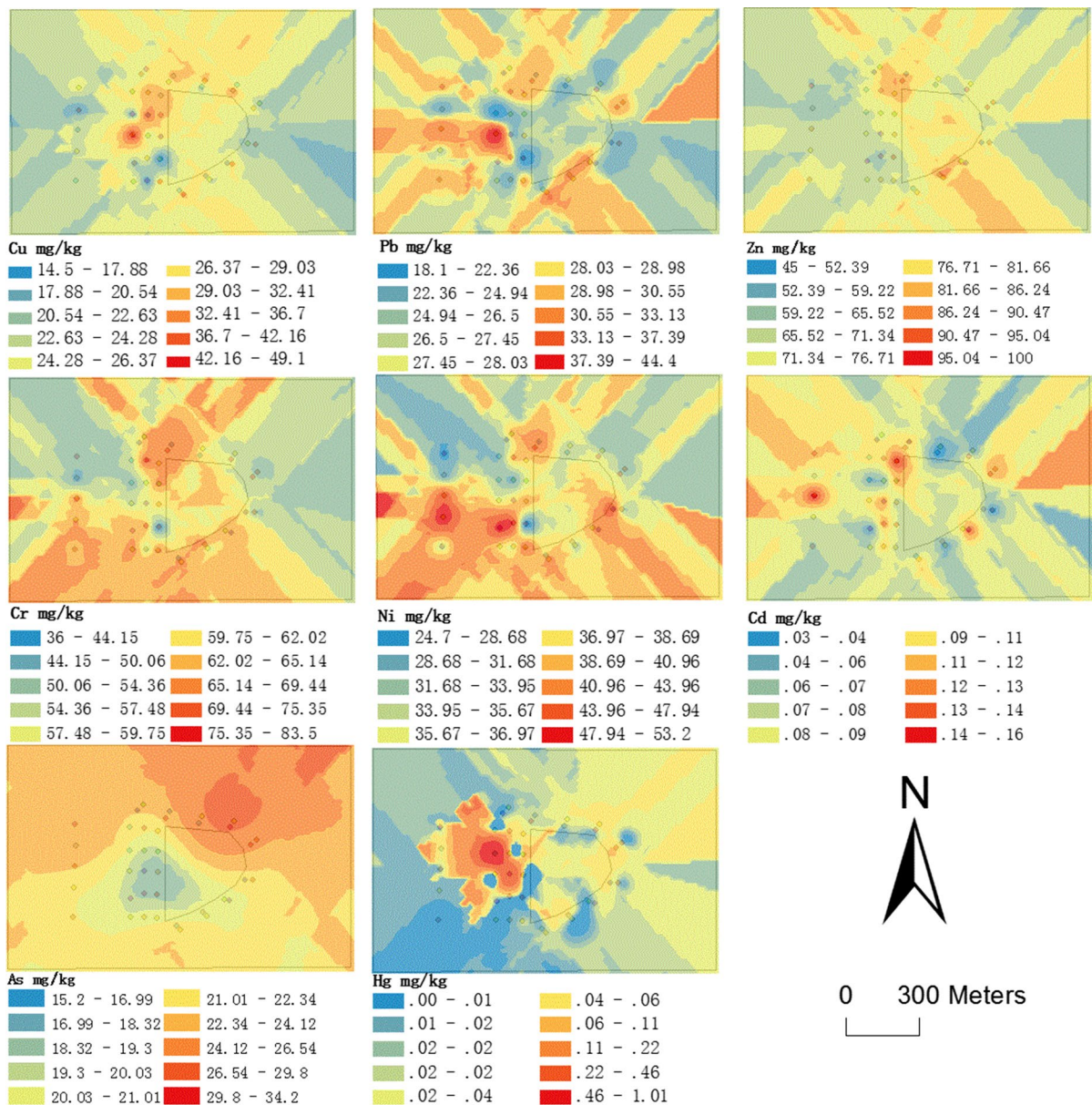


Fig. 2 Horizontal distribution characteristics of heavy metals in landfill soil

landfill site overturns more, while the north, east and south sides are almost not disturbed by human factors due to the high terrain. It can be inferred that the high content of heavy metals may be due to natural factors. The distribution of heavy metals in soil is different in different directions, which is mainly affected by natural and human activities, and human factors are more important (Lee et al., 2011). Moreover, the content of heavy metals in

soil will increase due to human factors (Hu et al., 2006; Kumari et al., 2015; Zhang et al., 2013).

Vertical distribution characteristics

According to the vertical distance, the soil in the west of the landfill is sampled and analyzed, and the results are shown in Fig. 3. The results show that the concentrations of As, Cr and Ni increase with

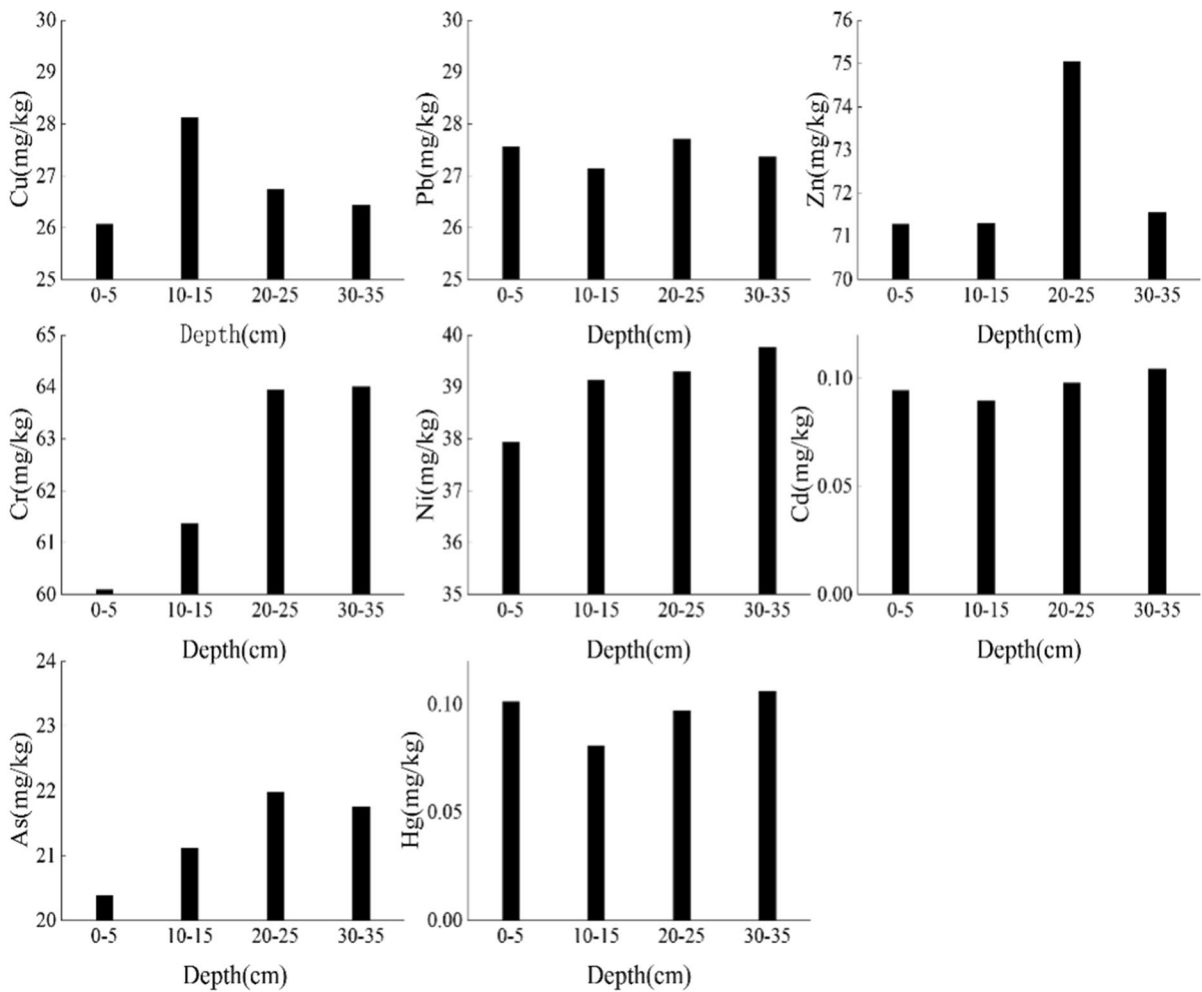


Fig. 3 Vertical distribution characteristics of heavy metals in landfill soil

depth. The concentration of Cu was the highest in the range of 10–15cm. The concentration of Zn was the highest in the range of 20–25cm. Heavy metals Cd and Hg showed the trend of decreasing first and then increasing. The fluctuation range of heavy metal Pb is very small. Zheng showed that the activity of heavy metal Pb in alkaline soil was low (Zheng et al., 2008). However, the soil in this study is strongly alkaline environment, so the concentration of heavy metal Pb does not change significantly with the depth of soil layer. In addition, Adelopo et al. (2018) showed that there was no significant correlation between soil heavy metal concentration and sample depth. However, some studies show that the heavy metal content in e-waste dismantling area and landfill will decrease with the increase in soil

depth (Wu et al., 2018b; Tu, 2013; Zhang, 2015c). The influencing factors of the source, migration and accumulation of heavy metals in the soil around the landfill site include climate, soil physical and chemical characteristics, wind direction, landfill time and volume, soil depth, season, distance from the landfill site, terrain and so on (Zhou, 2020). The topsoil in the range of 0–35cm in the study area shows that the deeper the soil layer, the content of heavy metals is the higher. The reason may be that the pH value changes the available content of heavy metals in soil to affect the activity and migration ability of heavy metals, and the higher pH value is easy to cause the precipitation of heavy metals (Wu et al., 2018b). In addition, it is possible that the sampling time is in summer, and the leaching phenomenon

caused by more seasonal rain makes the vertical migration of heavy metals in the soil, resulting in higher content of heavy metals in deep soil.

Pollution assessment

Evaluation results of Geo-accumulation index

Through the analysis of ground accumulation index, the elements show significant changes, and the results are shown in Fig. 4. The average value is -0.921 (Cr) to -0.345 (Ni), while the minimum and maximum values are -3.329 (Hg) and 5.070 (Hg), respectively. It can be seen that the change of element Hg is very significant, which is similar to the results shown by Wang et al. (2020) in the study of other regions of Tibet. Other studies have shown that there are significant differences in the pollution degree of element Hg, ranging from no pollution to severe pollution (Xiao et al., 2019). The other seven elements showed mild pollution. In addition, the pollution degree of the

ground accumulation index of 8 elements is divided in proportion, as shown in Table 1. In the 98 sampling sites, the average value of Cr accumulation index was less than 0, which belonged to non-pollution. The accumulation of Pb, Zn, Ni, Cd and As in soil reaches 0–1, which belongs to light pollution state. The accumulation index of heavy metal Cu in 9 sites belongs to light pollution, and 1 site belongs to moderate pollution. There were 4 samples with Hg accumulation index greater than 5, which indicated that heavy metal Hg had different degrees of pollution contribution around the landfill. Barbieri et al. (2014) also showed that Hg pollution was the most serious. It can be seen that the impact of human activities on soil cannot be ignored.

Evaluation results of Nemerow comprehensive pollution index

Because the soil in the study area is affected by Cu, Pb, Zn, Cr, Ni, Cd, As and Hg, the comprehensive

Fig. 4 Box-plots of I_{geo} in soil of landfill

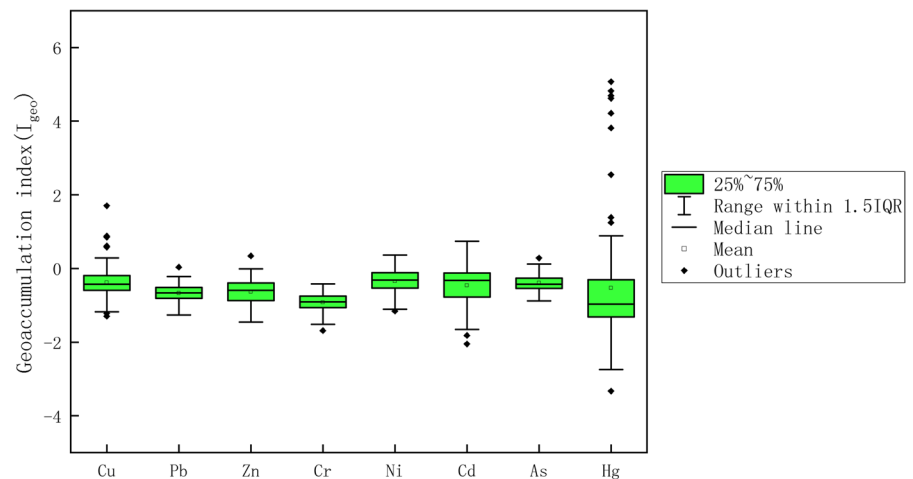


Table 1 Proportion of each element in different pollution degree

Pollution level		Cu	Pb	Zn	Cr	Ni	Cd	As	Hg
Unpolluted	<0	89.80%	98.98%	98.98%	100%	85.71%	76.53%	93.88%	80.61%
Unpolluted-Moderately polluted	0–1	9.18%	1.02%	1.02%	0	14.29%	23.47%	6.12%	9.18%
Moderately polluted	1–2	1.02%	0	0	0	0	0	0	3.06%
Moderately heavily polluted	2–3	0	0	0	0	0	0	0	1.02%
Heavily polluted	3–4	0	0	0	0	0	0	0	1.02%
Heavily extremely polluted	4–5	0	0	0	0	0	0	0	4.08%
Extremely polluted	>5	0	0	0	0	0	0	0	1.02%

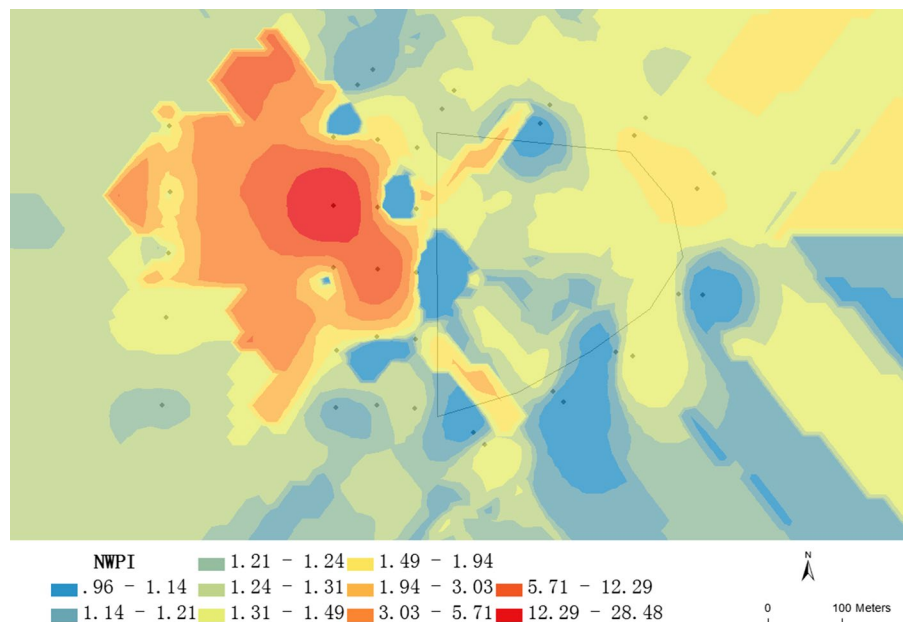
pollution assessment is carried out. Nemerow comprehensive pollution index method is used to evaluate the results of each point, as shown in Table S6. It can be seen from the table that the average value of the comprehensive pollution index is 2.969, belonging to the moderate pollution level. Figure 5 shows the Nemerow comprehensive pollution assessment of heavy metals in the soil around the landfill site. It can be seen from Fig. 5 that the sites with moderate and severe pollution are located in the west side, close to the domestic waste acquisition station. It also shows that the influence on the west side of the landfill is greater than that on other directions, which may be related to the westward slope of the whole landfill.

Evaluation results of potential ecological risk index

The statistical results of single heavy metal pollution index of 98 soil samples around the landfill are shown in Table S7. It can be seen from Table S7 that the order of average value of single potential ecological risk index of heavy metals is Hg, Cd, As, Cu, Ni, Pb, Cr, Zn. The potential ecological risk index of As, Cu, Ni, Pb, Cr and Zn is less than 40, which belongs to low hazard level. Only the potential ecological risk index of heavy metals Hg and Cd is more than 40, which also indicates that there may be ecological risk of these heavy metals in the soil around the

landfill site. The reason why the soil around the landfill site is more likely to be harmed by heavy metals Cd and Hg may be related to the electronic wastes such as fluorescent lamps and batteries contained in domestic waste. It is also possible that lead is directly transferred from municipal solid waste including battery and electronic equipment waste in landfills (Wang et al., 2020). Then, the heavy metals Cd and Hg and the total potential ecological risk were analyzed, as shown in Fig. 6. The figure shows that the potential ecological risk index results of heavy metals Cd and Hg are in the downstream area of the landfill. It can be seen from the third figure in Fig. 6 that the area with strong potential ecological risk index is also located in the downstream area of the landfill. Through the evaluation of the single potential ecological risk index and the total potential ecological risk index of the eight heavy metals in the landfill, it is found that the ecological risk in the downstream of the landfill is greater than that in other directions. Therefore, it shows that the soil in the downstream area of the landfill is very likely to be affected, and it is necessary to strengthen the supervision of the soil in the downstream area of the landfill.

Fig. 5 Results of Nemerow Comprehensive Pollution index evaluation



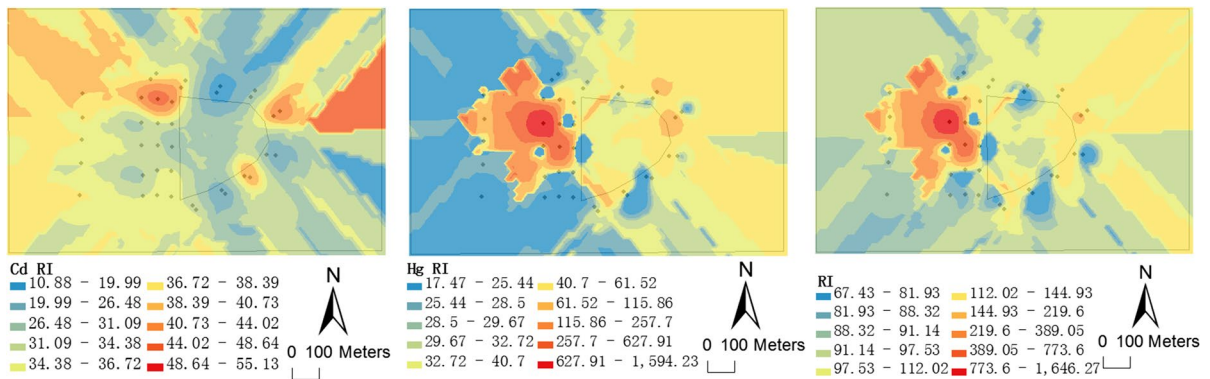


Fig. 6 Evaluation of potential ecological risk index of heavy metals Cd and Hg

Table 2 Correlation statistical analysis results

Element	Cu	Pb	Zn	Cr	Ni	Cd	As	Hg
Cu	1	0.433**	0.515**	0.280**	0.078	0.242*	-0.036	-0.08
Pb	0.433**	1	0.618**	0.442**	0.248*	0.387**	0.128	-0.097
Zn	0.515**	0.618**	1	0.655**	0.262**	0.400**	0.009	-0.081
Cr	0.280**	0.442**	0.655**	1	0.785**	0.303**	-0.285**	-0.049
Ni	0.078	0.248*	0.262**	0.785**	1	0.106	-0.385**	0.029
Cd	0.242*	0.387**	0.400**	0.303**	0.106	1	0.039	-0.165
As	-0.036	0.128	0.009	-0.285**	-0.0385**	0.039	1	-0.063
Hg	-0.08	-0.097	-0.081	-0.049	0.029	-0.165	-0.063	1

** Two-tailed correlation was significant at the 0.01 level.

* Two-tailed correlation was significant at the 0.05 level.

Possible source analysis of heavy metals

The correlation analysis results of heavy metal elements Cu, Pb, Zn, Cr, Ni, Cd, As and Hg are shown in Table 2. It could be seen that there is a significant correlation between Cu, Pb and Zn in the soil around the landfill. Among them, Pb and Cu are chalcophile elements, and the same elements have some similarities in supergene geochemistry (Chen et al., 2015). There was a significant correlation between Pb and Zn, Cr, Cd in the soil around the landfill. There was a significant correlation between Zn and Cr, Cd in the soil around the landfill. There was a significant correlation between Cr and Ni in the soil around the landfill. Therefore, there was a significant correlation between Cu, Pb, Zn, Cr, Ni and Cd. It is possible that the sources of these six heavy metals are the same. However, there was no significant correlation between As and Hg and other heavy metals, indicating that the sources were different. Lv et al. (2019b) also showed that there was a negative correlation between Hg and other

elements in the soil around the waste incineration plant. Zhao et al. (2015) also found that there was a significant negative correlation between Hg and As, Cr, Cu and Zn in the soil around the incineration plant. In addition, Jin et al. (2018) studied the content and source of heavy metals in rural garbage, which showed that As and Hg were not related to other elements, indicating that the sources of Hg were different.

Based on the results of correlation analysis, heavy metals in soil were extracted to analyze the sources of heavy metal pollution. The results are shown in Table 3. After the orthogonal rotation normalized by Kaiser, three principal components with eigenvalues greater than 1 are obtained. The contribution rates were 32.384, 24.046 and 13.352%, respectively, and the cumulative contribution rate was 69.783%, which indicated that the results could be used to analyze the sources of heavy metals in landfill soil.

The highest contribution rate of component 1 was 32.384%. The heavy metals with higher load were Cu (0.582), Pb (0.736), Zn (0.836), Cr (0.856), Ni

Table 3 Principal component analysis of eight heavy metals in landfill

Category	Rotating principal component		
	1	2	3
Cu	0.582	0.326	0.217
Pb	0.736	0.349	0.153
Zn	0.836	0.225	0.152
Cr	0.856	−0.372	−0.041
Ni	0.613	−0.652	−0.09
Cd	0.533	0.328	−0.225
As	−0.185	0.729	0.164
Hg	−0.141	−0.311	0.893
Eigenvalue	2.591	1.924	1.068
Variance contribution rate%	32.384	24.046	13.352
Total Variance Explained%	32.384	56.43	69.783

The load is greater than 0.5

(0.613) and Cd (0.533). It can be inferred that the sources of these heavy metals are similar. The sources of these heavy metals may be closely related to the existence of batteries, waste tires, ink and plastics in landfills (Ma et al., 2018).

The contribution rate of component 2 is 24.046%, and As is one of them. In addition, the element in Table S5 shows low variation and is less affected by human activities. There was no correlation between as and other seven heavy metals. It is speculated that the heavy metal element as in soil is more likely to be affected by the factors of soil forming parent material in nature. Some studies also show that there is a high concentration of as in the soil of the Qinghai Tibet Plateau, which may be related to the high soil background value (Zhang et al., 2012; He et al., 2016). Other scholars have shown that the content of As in the eastern, southern and southwestern parts of the Tibetan Plateau is higher, and the reason for the higher content is related to the natural soil forming factors (Sheng et al., 2012).

The contribution rate of component 3 was 13.352%, and the load of heavy metal Hg was 0.893. This element shows strong variation in Table S5, indicating that it is greatly influenced by human activities. There was no correlation with the other seven heavy metals. It can be inferred that the source of heavy metal Hg in this study area is likely to be human factors. According to the field observation, it is found that waste products are collected on the

west side of the landfill, and the west side is greatly affected by human beings, which may also lead to the high content of heavy metal Hg in the soil around the landfill. Therefore, it is speculated that the following three reasons may increase the content of metal elements in the soil on the west side of the landfill site: First, incineration of waste can remove metals with recycling value. Volatile Hg elements are produced in the incineration process, and their migration and settlement will increase the Hg content in the soil. Second, the waste liquid discharged from the waste acquisition station may increase the content of heavy metals in the surrounding soil. Third, a large number of metal wastes are stacked outside the waste acquisition station.

Conclusion

This study is the first time to conduct a statistical analysis of heavy metals in the soil of Shannan landfill in Tibet Plateau, including the horizontal and vertical contents of heavy metals in the soil around the landfill, the potential ecological risk and the spatial distribution characteristics of pollution.

- (1) The contents of heavy metals Zn, Cr, Ni, Pb, Cu, As, Cd and Hg in the soil around Luqiong-gang landfill in Shannan city were monitored. The results showed that the average content of heavy metals in landfill soil was lower than the risk screening value of national soil environmental quality standard (GB 15618-2018). In the horizontal direction, the closer to the landfill, the concentration of heavy metals in the soil is higher. In the range of 0-35cm depth of topsoil, the content of heavy metals As, Cr and Ni obviously increases with the increase in depth.
- (2) The results of geo-accumulation index showed that 8 heavy metals in all sites were polluted to different degrees. However, the average value of land accumulation evaluation of 8 kinds of heavy metals is less than 0. The order of the average value of single hazard pollution index of soil heavy metals is Hg > Cd > As > Cu > Ni > Pb > Cr > Zn. The average value of the comprehensive pollution index is 2.969, and the value is between 2 and 3, belonging to the moderate pollution level. The area greatly affected is the west side

of the landfill. The total potential risk of landfill belongs to the medium pollution hazard level, and the pollution impact in the downstream area of the landfill is greater than that in other areas of the landfill.

- (3) There is a significant correlation between the six heavy metals Cu, Pb, Zn, Cr, Ni and Cd in the soil around the landfill. However, there was no significant correlation between As, Hg and the other six heavy metals. The high content of heavy metal As may be related to natural soil forming factors, and the high content of heavy metal Hg may be related to human factors.

To sum up, through the analysis of the content of heavy metals in the soil of Shannan landfill, we know that the soil around the landfill has been affected to a certain extent. The ecological environment of the Qinghai Tibet Plateau is relatively fragile, so we need to pay attention to the ecological environment all the time.

Author contributions Zeng Dan and Guanyi Chen provided the research ideas and experimental equipment. Wenwu Zhou, Dean Meng, Peng Zhou, Keke Chang, Qiongda Zhuoma, Jing Wang, and Fei Xu completed the experimental operation and the arrangement and processing of experimental data.

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Data Availability All relevant data are within the manuscript and available from the corresponding author upon request. Supplementary information is available at Environmental Geochemistry and Health's website.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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.

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