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Utilization of Humus-amended Green Soil for Stabilized Landfill in Tibet and Risk Evaluation

Xinru SUN, Huijun XI, Weipan LIU, Di WU, Peng ZHOU*, Zeng DAN

School of Ecology and Environment, Tibet University, Lhasa 850000, China

Abstract [**Objectives**] With the rapid development of the economy and urbanization, the resource utilization of humus from landfills in Tibet faces significant challenges. This paper aims to study the utilization of humus-amended green soil for stabilized landfill in Tibet and evaluate its risk. [**Methods**] This paper focuses on the humus soil of a stabilized landfill in Lhasa, conducting soil chemical characterization and mixed amelioration tests with various amelioration materials to evaluate the potential of the treated soil for application in greening and its associated ecological risks. [**Results**] The findings indicate that the humus soil is nutrient-rich; however, the levels of heavy metals are concerning. By experimenting with different ratios of fly ash and green soil, it was determined that a 5 : 5 ratio markedly improved the water permeability and retention of the humus soil, significantly reduced the heavy metal content, and lowered the ecological risk index, thus demonstrating the effectiveness of the amelioration measures. [**Conclusions**] This study provides an experimental basis for the resource utilization of landfill humus, highlights the necessity of creating eco-friendly soil, and holds substantial theoretical and practical significance for the sustainable development of Tibet and similar regions.

Key words Landfill humus soil; Improvement; Greenfield soil; Ecological risk

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Alongside population growth, rapid urbanization, industrialization, lifestyle changes, and economic expansion, the generation of global solid waste is increasing annually. Landfills, characterized by their low investment costs and straightforward operational processes, have been widely adopted for municipal waste disposal in both developing and developed countries[1 – 3]. Over the past 40 years, approximately 8 billion t of municipal waste have been landfilled in China[4 – 5]. When domestic waste is landfilled for several decades (typically more than 8 – 10 a in the southern region and over 10 – 15 a in the northern region), the easily degradable substances within the waste will be completely or nearly completely decomposed. Consequently, the settlement of the landfill surface will be minimal (less than 1 – 5 mm/a), and the volume of leachate and gas produced by the waste will be either very small or nonexistent. Additionally, the content of biodegradable materials (BDM) in the waste will decrease to below 3%, and the leachate's chemical oxygen demand (COD) concentration will fall to less than 25 – 50 mg/L, indicating that stabilization has essentially been achieved[6 – 7]. Research indicates that the primary components of stabilized, aged landfill waste include humus, rubber and plastic, wood and bamboo, glass, and metal, with humus content reaching as high as 65% – 75%[8]. Due to the degradation of organic matter in the landfill, humus exhibits a high organic matter content, is rich in nitrogen, phosphorus, and potassium (NPK), and contains a variety of microorganisms. The leachate produced is weakly alkaline[9 – 11], possessing characteristics akin to fertile loam, making it suitable for use as garden planting soil. However, it is important to note that humus soil often contains heavy metal levels that exceed regulatory standards, posing potential secondary pollution risks[12 – 14].

As a crucial ecological security barrier and a national ecological civilization highland in China, Tibet serves as a significant "water tower" that sustains ecosystems and supports social and economic development not only in China but also in Southeast and South Asia[15 – 16]. Consequently, Tibet plays a pivotal role in maintaining ecosystems both within China and across Asia[17 – 19]. However, due to the sparsely populated Tibetan Plateau, domestic waste is predominantly landfilled, with over 140 sanitary landfills currently in operation alongside several stockpiled landfills[20]. In recent years, the rapid economic development in Tibet, coupled with an overall improvement in the quality of life, has rendered the existing landfills inadequate to manage the current volume of domestic waste. This situation presents two primary challenges: first, the saturation of existing landfill capacities and the associated difficulties in site selection; and second, the inability to utilize landfill waste resourcefully and sustainably. Given the importance of protecting Tibet's ecological environment and the necessity for resource utilization of landfill waste within this unique natural context, this study focuses on the domestic sanitary waste landfill in Lhasa, Tibet, which was closed at the end of 2018. The research proposes to conduct soil improvement and Arabidopsis planting tests by excavating and sampling the landfill. This will be based on an analysis of the chemical characteristics of the landfill humus soil to evaluate the safety of its application in soil greening. The

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* Corresponding author.

ultimate goal is to provide a conceptual framework for the reuse of humus soil from landfills in Tibet, advocating for the perspective that landfills should serve as sites for waste transfer and treatment rather than as final disposal destinations.

1 Sample collection and methods

1.1 Sample collection and chemical analysis The sanitary landfill for domestic waste in Lhasa City is characterized by varying landfill ages and significant differences in the degree of decomposition, with landfill durations ranging from 5 to 20 a. Most of the landfilled waste has either completely reached or is nearing a stabilized state. Through site investigations of the landfill, combined with assessments of waste distribution, landfill depth, and landfill age, three representative sampling points were selected in the horizontal direction of the landfill, specifically those with a landfill duration exceeding 15 a. Sampling depths of 1, 2, 3, 4, and 5 m were established. An excavator was used to excavate the refuse piles, and sampling was conducted in accordance with the quadratic method outlined in the *Sampling and Analysis Methods of Domestic Garbage* (CJ/T 313 – 2009). In total, 15 representative samples were collected (Fig. 1), with 50 kg of material obtained from each sampling point. All samples underwent sieving through a 60-mesh sieve, and the sieved material was subsequently analyzed for physicochemical properties, with the analytical methods detailed in Table 1.

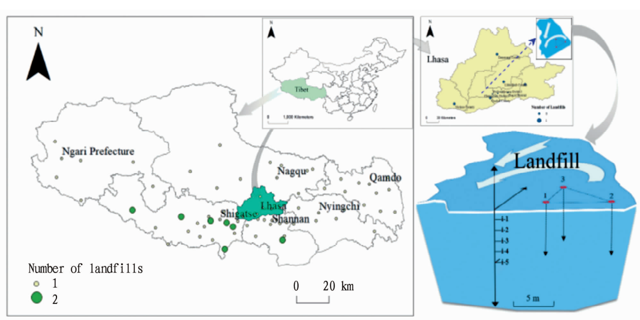


Fig. 1 Landfill location and sampling site layout

1.2 Experimental setup and methodology

1.2.1 Selection of improved materials. Fly ash is a waste product generated from the high-temperature combustion of pulverized coal in thermal power plants. Studies have demonstrated that fly ash possesses several beneficial characteristics, including smaller particle size, low bulk weight, and the presence of essential plant nutrients such as calcium, magnesium, and potassium. Additionally, it can neutralize acidity and react with heavy metals in the soil to form stable compounds. These properties contribute to the enhancement of soil pore structure, increased water-holding capacity, improved microbial activity, provision of necessary nutrients for plant growth, and reduction of the bioavailability of heavy metals, thereby mitigating their environmental and health risks. Furthermore, as a significant by-product of coal-fired power plants, the application of fly ash as a soil conditioner can decrease waste accumulation and environmental pollution, promoting resource reuse[21–23].

Conventional green soil, rich in organic matter and key nutrients such as nitrogen, phosphorus, and potassium (NPK), supports a diverse array of microorganisms that improve soil structure, enhance water retention, and increase permeability, thereby creating an optimal environment for plant growth. Additionally, it helps to mitigate the threat posed by invasive species, making it an environmentally friendly option.

In this study, humus amendment materials were derived from fly ash and green soil. The mass ratios of humus to fly ash were 3 : 7, 4 : 6, 5 : 5, 6 : 4, and 7 : 3, establishing the No. 1 amendment group, referred to as HS : FA. Similarly, the No. 2 amendment group was created using the same ratios of humus to green soil, denoted as HS : GS. Additionally, two control groups were established, consisting of original humus soil and green soil. Following an analysis of humic acid, pH, conductivity, and heavy metal content in the amended groups, pot planting experiments were conducted using Arabidopsis thaliana seeds. Regular watering was performed without the application of additional nutrients. The plants were harvested on the 28^{th} day of growth, at which point chlorophyll content was measured.

1.2.2 Indicators and methods for analyzing the chemical properties of humus and improved soils. The chemical properties of humus and improved soils were analyzed as described in Table 1.

1.2.3 Ecological risk assessment of improved soil. Potential Ecological Risk Assessment (PERA) is a method proposed by Hakanson *et al*. to quantitatively evaluate the degree of potential ecological harm caused by pollutants[24]. This method reflects not only the impact of individual heavy metal elements in a specific environment but also the combined effects of multiple heavy metal elements. Furthermore, the degree of potential ecological harm can be determined through a quantitative approach, calculated using a specific formula.

$$RI = \sum_{i}^{m} E_r^i = \sum_{i}^{m} \left(T_r^i \times \frac{C_{0-1}^i}{C_b^i} \right)$$

where RI is the potential ecological hazard index; E_r^i is the pollution degree of pollutant i; T_r^i is the toxicity response coefficient of heavy metal i; C_{0-1}^i is the measured content of heavy metal i (mg/kg), and C_b^i is the reference ratio of heavy metal i. The background value of Lhasa soil environment was used[25]. Referring to related studies, the TERs of As, Hg, Sb, Cu, Pb, Cd, Ni, Zn, and Tl were 10, 40, 40, 5, 5, 30, 5, 1, and 40, respectively. The classification criteria of E_r^i and RI are shown in Table 2.

3 Results and analysis

3.1 Chemical properties of humus The chemical characteristics of humus soil indicated that the pH ranged from 7.76 to 8.11, classifying it as weakly alkaline. This alkalinity may influence the availability of nutrients to vegetation. The mean total nitrogen (TN) content was found to be 3.06 g/kg, suggesting variability in the composition of organic matter and its progressive decomposition at different soil depths[26]. Phosphorus, an essential nutrient for plant growth and soil health, reached a maximum concentration of 68.90 mg/kg in the humus, indicating that stabilized landfill humus has the potential to enhance soil productivity.

Notable differences were observed in the concentrations of heavy metals (arsenic, chromium, cadmium, copper, zinc, mercury, nickel, lead) within the humus. The highest concentration of chromium (Cr) recorded was 143.92 mg/kg, while the mean concentration of cadmium (Cd) was 0.26 mg/kg, which remains below the regulatory threshold of soil environmental standards but exceeds the background value for the soil environment in Lhasa. Copper (Cu) and zinc (Zn) concentrations were relatively high, with mean values of 29.00 and 36.77 mg/kg, respectively, whereas lead (Pb) and nickel (Ni) concentrations were lower, with mean values of 21.11 and 5.12 mg/kg, respectively. In comparison, heavy metal concentrations in humus from landfills in Tibet were lower than those reported in studies of landfills in industrial areas of East China, where chromium concentrations exceeded 200 mg/kg and lead concentrations were significantly higher[27]. This discrepancy may reflect regional variations in industrial activities, waste composition, and regulatory practices.

Table 1 Indicators and methods of physical and chemical analysis

Category	Indicators	Methodology
Humus (soil)	TN, effective nitrogen	Automatic Kjeldahl nitrogen determination
	TP	Alkali fusion——molybdenum antimony antispectrophotometric method
	Quick-acting phosphorus	Molybdenum antimony antimony spectrophotometry
	TK	Alkali fusion
	Quick-acting potassium	Ammonium acetate - flame photometric method
	SOM	Volumetric method using potassium dichromate
	Heavy metal	*Determination of Metal Elements in Solid Wastes——Inductively Coupled Plasma Mass Spectrometry* (HJ 766 - 2015), *Determination of Mercury, Arsenic, Selenium, Bismuth and Antimony in Solid Wastes——Microwave Extinction/Atomic Fluorescence Method* (HJ 702 - 20114)
Improved soil	Permeability	The mixed soil samples with different ratios were evenly added to a 50 ml colorimetric tube, and then 20 ml of distilled water was added to it, and the percolation distance of the distilled water in every minute was the permeability of the medium
	Water retention rate	30 ml of distilled water was injected into 30 g of mixed soil samples with different ratios to mix the two components well, and the mixed samples were filtered and weighed after standing for 3 h at room temperature. The water content per unit mass of medium is the water retention rate of the medium
	Humic acid	*Determination of Soil Humus Composition by Sodium Pyrophosphate - Sodium Hydroxide Extraction of Potassium Dichromate Oxidizing Capacity Method* (NY/T 1867 - 2010) and *Soil Organic Matter Determination Method* (NY/T 85), and the content of fulvic acid and huminic acid were obtained by measuring them sequentially
	Chlorophyll	The plant leaves were cut, ground, extracted and filtered, after which the absorbance of the extract at different wavelengths was measured using a UV spectrophotometer, and the plant chlorophyll content was calculated from the absorbance
	pH	*Determination of Soil pH by Potentiometric Method* (HJ 962 - 2018)
	Conductivity	*Determination of Electrical Conductivity of Soil Electrode Method* (HJ 802 - 2016)

Table 2 Criteria for categorization of ecological risk assessment of heavy metals

E_r^i	Pollution level	RI	Pollution level
$E_r^i < 40$	Minor ecological hazard	$RI < 150$	Minor ecological hazard
$40 \leqslant E_r^i < 80$	Medium ecological hazard	$150 \leqslant RI < 300$	Medium ecological hazard
$80 \leqslant E_r^i < 160$	Strong ecological hazard	$300 \leqslant RI < 600$	Strong ecological hazard
$160 \leqslant E_r^i < 320$	Serious ecological hazard	$RI \geqslant 600$	Serious ecological hazard
$E_r^i \geqslant 320$	Extreme ecological hazard		

3.2 Water permeability and water retention of different modified substrates Water permeability serves as a crucial indicator of soil permeability. Excessively high permeability indicates that soil pores are too large to retain water, while excessively low permeability can result in soil erosion, potentially leading to plant mortality due to insufficient oxygen. In this experiment, campus green soil was utilized as the control group. As illustrated in Fig.2, the water permeability of humus soil exceeds that of green soil. Furthermore, after enhancing the humus soil with the addition of fly ash and green soil, a significant reduction in water permeability was observed across all substrate groups. This reduction generally exhibited a trend of increasing permeability with higher percentages of improved materials. This phenomenon may be attributed to the decrease in particle size of the materials following enhancement, particularly when the ratio of humus soil to fly ash was 5 : 5. At this ratio, the water permeability closely approximated that of green soil, suggesting that this combination yields the optimal water permeability.

Water retention is a key indicator used to evaluate a soil's capacity to retain moisture. An excessively high water retention rate can lead to excessive soil moisture, ultimately resulting in plant death, while an excessively low rate can hinder the soil's ability to store water, causing plant death due to insufficient moisture. As illustrated in Fig. 3, the water retention rate of humus soil is higher than that of green soil. Furthermore, the addition of fly ash and green soil to enhance the humus soil resulted in a decrease in the water retention rate across all improved substrate groups. Notably, the ratios of humus soil to green soil at 5 : 5 and 7 : 3 are closest to that of green soil, suggesting that these ratios may represent the optimal water retention rates.

Table 3 Chemical characterization of humus soils

Indicators	0 – 1 m	1 – 2 m	2 – 3 m	3 – 4 m	4 – 5 m	Mean value	Standard deviation
pH	8.110	7.990	7.940	7.990	7.760	7.960	0.130
TN // g/kg	1.580	5.070	2.080	2.680	3.870	3.060	1.410
Effective nitrogen // mg/kg	474.300	410.270	464.780	553.860	388.020	458.250	64.570
TP // g/kg	1.360	1.320	3.600	3.710	3.230	2.650	1.200
Quick-acting phosphorus // mg/kg	45.960	64.730	60.960	60.470	68.900	60.200	8.660
TK // g/kg	13.340	10.450	14.220	13.53	13.960	13.100	1.520
Quick-acting potassium // mg/kg	978.100	1 031.420	2 541.000	1 381.490	1 819.140	1 550.230	647.870
SOM // g/kg	47.460	67.320	78.620	76.710	96.600	73.340	17.930
As // mg/kg	5.388	8.488	5.602	4.998	8.060	6.510	1.630
Cr // mg/kg	71.564	92.858	143.920	114.25	108.514	106.220	26.790
Cd // mg/kg	0.234	0.462	0.264	0.242	0.100	0.260	0.130
Cu // mg/kg	11.086	21.846	86.894	12.704	12.456	29.000	32.650
Zn // mg/kg	24.726	33.860	77.022	24.926	23.310	36.770	22.890
Hg // mg/kg	0.346	0.354	0.308	0.258	0.236	0.300	0.050
Ni // mg/kg	3.614	6.690	6.340	3.470	5.506	5.120	1.510
Pb // mg/kg	7.816	19.828	44.942	18.196	14.790	21.110	14.100

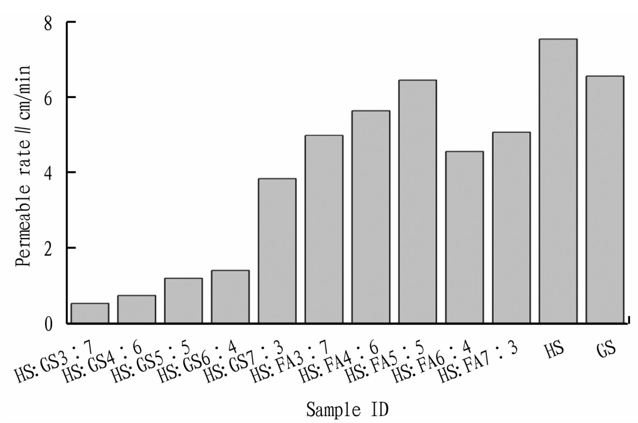


Fig. 2 Water permeability of each improved substrates

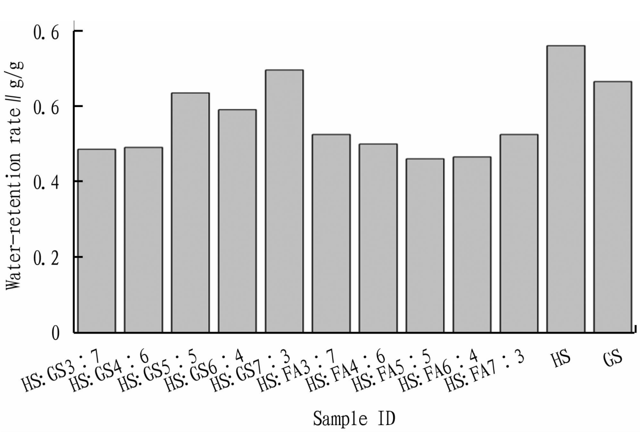


Fig. 3 Water retention rate of each improved substrates

3.3 Humic acid content of different modified substrates Humic acid primarily consists of fulvic acid, humic acid, and humin, all of which can promote plant growth to a certain extent, exhibiting effects similar to those of growth factors. Additionally, humic acid has the ability to complex with and adsorb heavy metals such as cadmium (Cd), lead (Pb), and zinc (Zn) in the soil. However, under varying conditions, humic acid can also activate the activity of Cd; specifically, humic acid can passivate Cd, whereas fulvic acid tends to increase the bioavailability of Cd in the soil[28]. Therefore, investigating the concentrations of each component of humic acid in humus soil can provide valuable insights into the bioefficacy of specific heavy metals in that environment.

Seen from Fig. 4, the total amounts of fulvic acid and humic acid in each group of amended substrates after humus amendment ranged from 4.40 to 9.54 g/kg. Specifically, the total amount of fulvic acid and humic acid in green soil was 6.58 g/kg, while in humus it was 3.97 g/kg. The fulvic acid content varied from 0.51 to 7.45 g/kg, with green soil containing 2.28 g/kg and humus containing 0.66 g/kg. In contrast, the humic acid content ranged from 1.88 to 6.12 g/kg, with green soil having a humic acid content of 4.3 g/kg and humus 3.31 g/kg. Notably, the fulvic acid content in all groups was higher than that of humus, except for the group with a humus to fly ash ratio of 6 : 4, where the fulvic acid content was slightly lower than that of humus. Furthermore, the fulvic acid content was higher than that of green soil for the ratios of humus to green soil of 3 : 7, 4 : 6, 5 : 5, and 6 : 4, as well as for the ratios of humus to fly ash of 4 : 6 and 7 : 3. In all other groups, the humic acid content in the amended substrates was slightly lower than that of the respective groups, with the exception of the humus to green soil ratio of 7 : 3 and the humus to fly ash ratios of 4 : 6, 5 : 5, and 6 : 4, where the humic acid content exceeded that of humus. Overall, the humic acid content in the remaining groups of amended substrates showed a slight decrease. In summary, the total concentrations of fulvic acid and humic acid in each group of improved substrates were greater than those found in humus, and overall, their content exceeded that of greening soil. Therefore, utilizing the improved landfill humus as a substrate for greening and planting is a viable option.

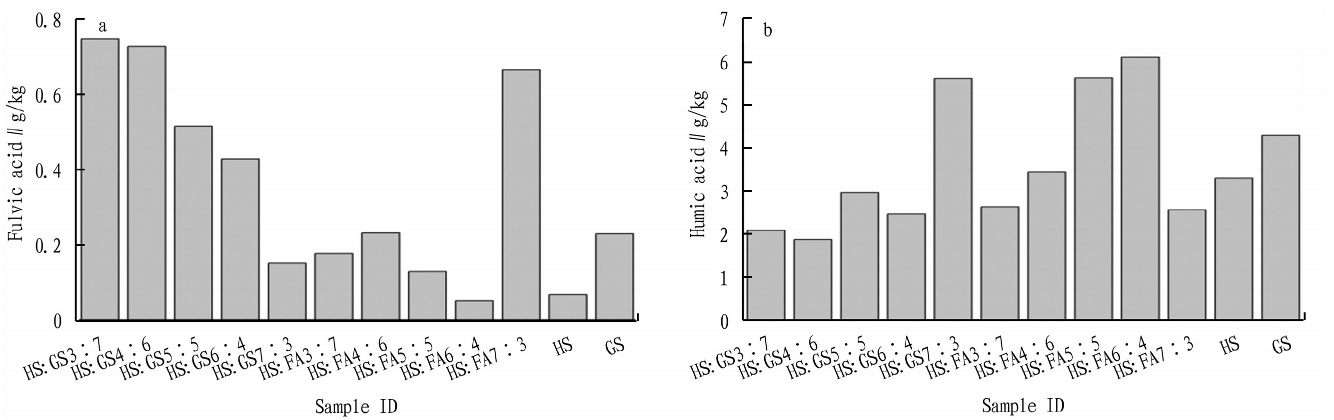


Fig.4 Fulvic acid (a) and humic acid (b) contents of each improved substrates

3.4 pH, conductivity and heavy metal content of different modified substrates The pH values of humus and greening soil in Lhasa landfill were both greater than 8 and weakly alkaline, in which the pH value of humus was slightly higher than that of greening soil. When humus and green soil mixed with each group of substrate, pH value have decreased, of which the ratios of humus and green soil are 3 : 7 and 4 : 6, pH value is closest to the green soil. When humus and fly ash mixed with each group of substrate, pH value is too high, are more than 10, which may be because the fly ash will make the soil pH value rise, is not conducive to plant growth. In addition, as shown in Table 4, the electrical conductivity (EC) value of the green soil of Lhasa campus was 49.6 mS/cm, while the EC values of humus soil before and after the amelioration were both higher, which may be due to the higher free metal ions in the humus soil. The level of conductivity reflects the level of soil salt content, and too high conductivity means that the soil salt is too high, thus inhibiting plant growth[29-30]. Therefore, if it wants to better resource utilization of humus soil, it needs to further regulate its pH and conductivity.

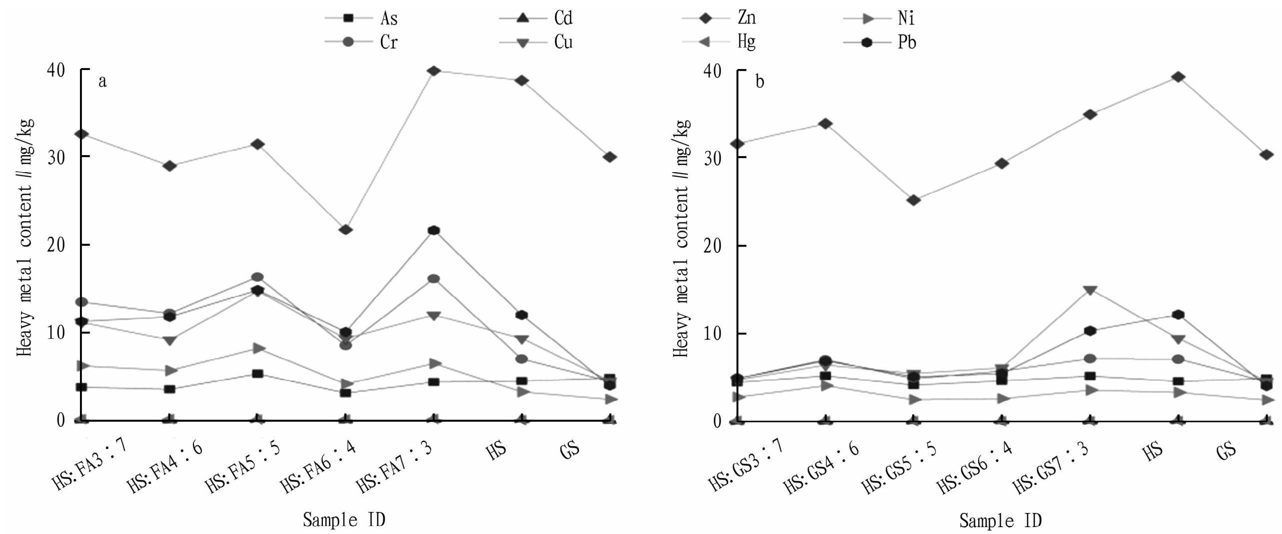
Table 4 pH and conductivity of each improved substrate

Proportion	HS : GS		HS : FA	
	pH	EC // μS/cm	pH	EC // μS/cm
3 : 7	8.10	213	11.00	1 027
4 : 6	8.03	285	10.96	945
5 : 5	7.93	398	10.74	946
6 : 4	7.88	634	10.56	898
7 : 3	7.74	1 065	10.05	792
10 : 0	–	–	8.52	848
0 : 10	8.07	49.6	–	–

The heavy metal contents in each group of amended soil are shown in Fig.5, except that the total amount of heavy metals was lower than that of green soil when the ratio of humus to green soil was 5 : 5, which was mainly due to the fact that the contents of As and Zn in the substrate were lower than that of green soil at this time, while the rest of the heavy metal contents were closer to that of green soil. The lower As content may be due to the fact that As (V) in the soil exists in the form of $H_2ASO_4^-$ and $HAsO_4^{2-}$ in alkaline environment, which can be stabilized by clay minerals adsorption[31]. While the nature of humus is similar to clay minerals, the lower Zn content may be due to the alkaline pH and increased organic matter content of the amended soil, which is conducive to the solidification of Zn into insoluble Zn in the soil, thus reducing its concentration[32]. When the ratio of humus to green soil was 5 : 5, the contents of As (4.20 mg/kg), Zn (25.18 mg/kg) and Hg (0.10 mg/kg) were lower than that of green soil (As: 4.95 mg/kg, Zn: 30.38 mg/kg, Hg: 0.11 mg/kg), and the contents of the rest of the heavy metals were lower than that of humus, which meet the requirements of Class II heavy metal content (pH > 6.5) in the *Green Planting Soil Standard* (CJ/T 340 – 2016).

3.5 Plant chlorophyll content Chlorophyll, which contains chlorophyll a and chlorophyll b, is the key to photosynthesis in plants, which is able to synthesize organic matter from carbon dioxide and water in the air under the action of sunlight, while releasing oxygen. In addition, studies have shown that changes in chlorophyll content can be used as an indicator for evaluating the ability of certain plants to survive under drought conditions and recover from water loss[33].

Since the pH value of the substrate with fly ash as the amendment material was too high for plant growth, the planting test was selected to be carried out in the green soil amendment group, and the two groups of green soil and humus soil were set as controls. The results showed that when the ratio of humus to green soil was 7 : 3 and when humus was the substrate, planting failed, while the rest of the groups had a lower survival rate, which might be caused by the high conductivity value in the substrate and thus inhibiting plant growth. When the ratios of humus to green soil were 3 : 7, 4 : 6, 5 : 5, 6 : 4 and when green soil was the substrate, total chlorophyll was 9.76, 27.40, 22.9, 23.77, and 14.60 mg/L. It can be seen that there was no obvious change pattern of chlorophyll content in each modified group, except that the chlorophyll content of *Arabidopsis thaliana* was lower than that of green soil when the ratio of humus to green soil was 3 : 7, and the rest of the groups were higher than that of green soil, which may be a result of the combined influence of water permeability, water retention rate, pH and other factors.



Note: a. HS : FA; b. HS : GS.

Fig. 5 Heavy metal content of each improved substrate

3.6 Results of the ecological risk assessment In the present study, the results of heavy metal content of amended humus from stabilized landfill showed significant changes. The contents of arsenic (As), chromium (Cr), cadmium (Cd), copper (Cu), zinc (Zn), mercury (Hg), nickel (Ni) and lead (Pb) in the amended humus were significantly lower than those in the original humus samples, which were as follows: arsenic decreased from 6.51 to 4.20 mg/kg, chromium decreased from 106.22 to 4.96 mg/kg, cadmium decreased from 0.26 to 0.09 mg/kg, and copper decreased from 29.00 to 5.00 mg/kg, zinc decreased from 36.77 to 25.18 mg/kg, mercury decreased from 0.30 to 0.10 mg/kg, nickel decreased from 5.12 to 2.53 mg/kg, lead decreased from 21.11 to 5.15 mg/kg (Table 5). These data not only show the effectiveness of the amelioration measures, but also indicate that the treated humus is closer to the background values and reduces the level of heavy metal contamination in the soil.

In terms of ecological risk evaluation, the potential ecological risk index (RI) of the improved humus soil was 70.16, which was significantly reduced compared with that of the original soil (215.53), indicating that soil remediation has achieved good results in reducing ecological risks (Table 5). The analysis of the ecological risk index of each heavy metal showed that the risk of heavy metals in the amended humus was significantly reduced, especially the danger of lead, cadmium and mercury was greatly reduced. This result provides strong data support for soil management and ecological restoration in Tibet, emphasizing the importance of heavy metal pollution management and its positive impact on environmental safety.

Table 5 Results of ecological risk assessment of amended soils

Item	As	Cr	Cd	Cu	Zn	Hg	Ni	Pb	
T_r^i	10.00	2.00	30.00	5.00	1.00	40.000	5.00	5.00	
HS : GS (5 : 5) // mg/kg	4.20	4.96	0.09	5.54	25.18	0.100	2.53	5.15	
HS // mg/kg	6.51	106.22	0.26	29.00	36.77	0.300	5.12	21.11	
Background value // mg/kg[25]	20.00	42.00	0.12	22.00	65.00	0.092	21.00	31.00	
E_r^i	As	Cr	Cd	Cu	Zn	Hg	Ni	Pb	RI
HS : GS(5 : 5)	2.10	0.24	23.00	1.26	0.39	41.74	0.60	0.83	70.16
HS	3.26	5.06	65.00	6.59	0.57	130.43	1.22	3.40	215.53

4 Conclusion

This study investigated the potential of humus from stabilized landfill in Tibet for amelioration and ecological risk assessment as green soil. Through the chemical characterization of the landfill humus, it was found that the humus was weakly alkaline and rich in nutrients (e.g., total nitrogen, phosphorus, and potassium), but the content of certain heavy metals (e.g., chromium, copper, and zinc) exceeded the standard, which posed a potential ecological risk. To address this situation, this study used fly ash and green soil as amended materials and set different mixing ratios. The results showed that the performance of the improved humus soil was improved in terms of water permeability and water retention, especially when the ratio of humus to green soil was 5 : 5, its performance was close to that of green soil, which made it show better adaptability in plant growth.

Meanwhile, this study investigated the removal effect of heavy metals. In the amended soil, the concentration of heavy metal elements was significantly reduced, and the potential ecological risk index (RI) decreased from 215.53 to 70.16, showing the effectiveness of soil remediation measures. This lays the foundation for the safe utilization of landfill humus and indicates that the treated soil is of great significance in ecological environmental protection. Meanwhile, the results of the study clarified the advantages and disadvantages among different amended substrates, which provides valuable reference basis for future soil treatment and resource utilization of landfills in Tibet and other regions.

References

[1] CHEELA VRS, JOHN M, DUBEY B. Quantitative determination of energy potential of refuse derived fuel from the waste recovered from Indian landfill[J]. Sustain Environ Res, 2021, 31: 1-9.

[2] YANG R, XU Z, CHAI J. A review of characteristics of landfilled municipal solid waste in several countries: Physical composition, unit weight, and permeability coefficient[J]. Pol J Environ Stud, 2018, 27(6): 2425-2435.

[3] OWUSU-NIMO F, ODURO-KWARTENG S, ESSANDOH H, *et al.* Characteristics and management of landfill solid waste in Kumasi, Ghana [J]. Scientific African, 2019, 3: 1-9.

[4] LI Q, MAO MM, HUANG X, *et al.* Refined resource treatment of stale domestic garbage: Technological progress and value research[J]. Journal of Public Management, 2022, 19(2): 142-153, 175.

[5] LI QH, SUN XJ, HU XY, *et al.* Study on the trend of carbon emission of municipal solid waste treatment in China[J]. Environmental Pollution & Control, 2023, 45(7): 952-958.

[6] WANG Y, HU J, YU CJ, *et al.* Character and resource utilization of mineralized aged refuse in a landfill in southwest[J]. Environmental Sanitation Engineering, 2023, 31(2): 36-40, 45.

[7] YOUCAI Z, HUA L, JUN W, *et al.* Treatment of leachate by aged-refuse-based biofilter[J]. Journal of Environmental Engineering, 2002, 128 (7): 662-668.

[8] LI M, WEI L. Research progress on the resource utilization of aged waste in domestic waste landfill[J]. China Resources Comprehensive Utilization, 2024, 42(6): 162-164.

[9] ZHAO YC, CHAI XL, NIU DJ. Characteristics of aged refuse in closed refuse landfill in Shanghai[J]. Journal of Tongji University (Natural Science), 2006(10): 1360-1364.

[10] KAARTINEN T, KAI S, RINTALA J. Case study on sampling, processing and characterization of landfilled municipal solid waste in the view of landfill mining[J]. Journal of Cleaner Production, 2013, 55(2): 56-66.

[11] QUAGHEBEUR M, LAENEN B, GEYSEN D, *et al.* Characterization of landfilled materials: Screening of the enhanced landfill mining potential [J]. Journal of Cleaner Production, 2013, 55: 72-83.

[12] JANI Y, KACZALA F, MARCHAND C, *et al.* Characterisation of excavated fine fraction and waste composition from a Swedish landfill[J]. Waste Management & Research, 2016, 34(12): 1292-1299.

[13] KACZALA F, MEHDINEJAD M H, LÄÄNE A, *et al.* Leaching characteristics of the fine fraction from an excavated landfill: Physico-chemical characterization[J]. Journal of Material Cycles and Waste Management, 2017, 19(1): 294-304.

[14] LIU XC. Study of stabilization characteristics and exploitability of landfilled municipal solid wastes[D]. Hangzhou: Zhejiang University, 2018.

[15] IMMERZEEL W, STOORVOGEL J, ANTLE J. Can payments for ecosystem services secure the water tower of Tibet[J]. Agric Syst, 2008, 96: 52-63.

[16] ZHANG LL, SU FG, YANG DQ, *et al.* Discharge regime and simulation for the upstream of major rivers over Tibetan Plateau[J]. J Geophys Res-Atmos, 2013, 118: 8500-8518.

[17] GENXU W, JU Q, GUODONG C, *et al.* Soil organic carbon pool of grassland soils on the Qinghai-Tibetan Plateau and its global implication [J]. Sci Total Environ, 2002, 291: 207-217.

[18] TAN K, CIAIS P, PIAO SL, *et al.* Application of the ORCHIDEE global vegetation model to evaluate biomass and soil carbon stocks of Qinghai-Tibetan grasslands [J]. Glob Biogeochem Cycles, 2010: 24, GB1013.

[19] YAO T, WU F, DING L, *et al.* Multispherical interactions and their effects on the Tibetan Plateau's earth system: A review of the recent researches[J]. Natl Sci Rev, 2015, 2: 468-488.

[20] DAN Z, ZHOU P, WANG J, *et al.* Investigation and analysis and evaluation of heavy metals in soil of sanitary landfill for domestic waste in Lhasa City[J]. Environmental Engineering, 2019, 37(11): 194-199, 154.

[21] LI L, JIANG ZQ. Physicochemical features and comprehensive utilization on fly-ash[J]. Research of Environmental Sciences, 1998(3): 65-67.

[22] WANG XF, ZHU GF, ZHANG HY. Study of the effect of amend regents on the combined pollution of heavy-metals[J]. Journal of Henan Normal University (Natural Science Edition), 2004(3): 133-136.

[23] ADRIANO DC, WEBER JT. Influence of fly ash on soil physical properties and turfgrass establishment[J]. J Environ Qual, 2001, 30(2): 596-601.

[24] HAKANSON L. An ecological risk index for aquatic pollution control [J]. Water Res, 1980, 14(8): 975-1001.

[25] CHENG HX, LI K, LI M, *et al.* Geochemical background and baseline value of chemical elements in urban soil in China[J]. Earth Science Frontiers, 2014, 21(3): 265-306.

[26] KJELDSEN P, BARLAZ MA, RINDT C, *et al.* Present and long-term composition of MSW landfills[J]. Waste Management & Research, 2002, 20(3): 225-240.

[27] LI Y, ZHOU L, WANG X. Heavy metal characteristics of refuse in municipal solid waste landfills: A case study in Eastern China [J]. Environmental Pollution, 2020, 265(Pt A): 114944.

[28] YU GF, JIANG X, SUN L. A review for effect of organic substances on the availability of cadmium in soils[J]. Acta Ecologica Sinica, 2002 (5): 770-776.

[29] LI WJ, WANG RY, HUANG J. Relationship between soil conductivity and spatial and temporal characteristics of groundwater depth of burial [J]. Agriculture and Technology, 2023, 43(7): 74-77.

[30] BHUYAN MI, MIA S, SUPIT I, *et al.* Spatio-temporal variability in soil and water salinity in the south-central coast of Bangladesh[J]. Catena, 2023, 222: 106786.

[31] LUO L, ZHANG SZ, MA YB. Advance in research on arsenic sorption and its affecting factors in soil[J]. Soils, 2008(3): 351-359.

[32] LIN L, CHEN SB. Transformation and influence factors of speciation of zinc in soils and its effect on zinc bioavailability: A review[J]. Journal of Agro-Environment Science, 2012, 31(2): 221-229.

[33] WU YH, HUANG GH, GAO J. Research advance in response and adaptation of bryophytes to environmental change[J]. Chinese Journal of Applied Ecology, 2001(6): 943-946.