Mongolian Journal of Agricultural Sciences, Vol.18, No.42 (2025)
https://doi.org/10.5564/mjas.v18i42.3689

Article

Preliminary study on the phytoremediation potential of *Reaumuria Soongorica* and *Nitraria Sibirica* for heavy metal reduction

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Received: 11.02.2025 Revised: 25.05.2025 Accepted: 10.06.2025

Abstract:
As part of efforts to monitor and mitigate environmental degradation caused by mining, an experimental study was conducted on reducing heavy metal concentrations in the tailings soil of the Oyu Tolgoi Mine. This mine is located in the Khanbogd soum, Umnugobi province, Mongolia. The study employed phytoremediation, an ecological engineering method that uses plants to extract or stabilize contaminants. Since soil contamination typically accumulates over long periods, two-year-old seedlings of two native plant species, *Nitraria sibirica Pall.* and *Reaumuria soongorica Pall. Maxim.,* were planted to evaluate their effectiveness in reducing heavy metal concentrations. A total of 96 seedlings were planted in two rows with 24 replicates each: one test site adjacent to the tailings facility and one control site located 5 km away. Heavy metal content in both the seedlings and the soil was analyzed over a five-month period by Hanlab LLC's Mineral Analysis Laboratory, Mongolia. Among the 28 heavy metals detected, the native shrub, *Reaumuria soongorica,* showed higher absorption and accumulation of arsenic, cadmium, lead, chromium, and nickel ranging from 65.4% to 82.7% compared to *Nitraria sibirica* (14.8% to 75.4%), indicating its potential as an effective species for phytoremediation in contaminated tailings soil.

Keywords: Heavy metals, soil pollution, phytoremediation, mine tailings, *Reaumuria soongorica*, *Nitraria sibirica*

Introduction

Soil contamination by heavy metals has become an increasingly critical environmental and public health issue, particularly in regions with intensive mining operations. In Mongolia, the rapid expansion of the mining sector has significantly contributed to economic development. However, this growth has also led to widespread environmental degradation, especially soil pollution in areas surrounding mining sites. Heavy metals in contaminated soils and water systems are known for their persistence, bioaccumulation in living organisms, and potential toxicity to both ecosystems and human health when their concentrations exceed permissible limits [1], [2].

Heavy metals are generally classified as either essential or non-essential based on their biological functions. Essential metals such as iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), and nickel (Ni) are required in trace amounts to support metabolic and physiological processes in living organisms [3], [4]. In contrast, non-essential metals such as cadmium (Cd), lead (Pb), arsenic (As), mercury (Hg), and chromium (Cr) serve no beneficial role in biological systems and are toxic even at low concentrations [5]–[9]. These elements can interfere with enzyme function, cellular respiration, and DNA integrity, leading to severe ecological and health impacts.

To mitigate soil contamination, phytoremediation has emerged as an environmentally friendly, cost-effective, and sustainable remediation technique. This ecological engineering approach utilizes plants with specific physiological traits to absorb, and groundwater [10], [11].

Reaumuria soongorica (Pall.) Maxim., and *Nitraria sibirica Pall.,* are native plant species widely distributed across Mongolia's arid and semi-arid regions. These species are well adapted to harsh environmental conditions, including drought, high salinity, and nutrient-poor soils, making them suitable candidates for ecological restoration and phytoremediation applications. Previous studies have demonstrated their remarkable tolerance to abiotic stress factors and their ability to survive in soils contaminated with heavy metals [12], [13].

Therefore, this study applies phytoremediation methods to reduce heavy metal content in the soil of the tailing's storage area at the Oyu Tolgoi Mine, while testing ecological engineering-based approaches for neutralizing pollutants as part of broader efforts to monitor and mitigate environmental degradation caused by mining activities.

Materials and Methodology

Study Area and Experimental Setup

The study was conducted near the Oyu Tolgoi LLC Tailings Storage Facility in Khanbogd soum, Umnugobi province, Mongolia. Two experimental plots (10 m × 20 m each) were established and fenced between May 11–13, 2024, to prevent external disturbances. Plot T1 was located adjacent to the tailings facility (contaminated), while Plot T2 was about 5 km away in a non-impacted area (control).

Experimental Design and Sampling Framework

Two local shrub species, *Reaumuria soongorica* (Pall.) Maxim. and *Nitraria sibirica* Pall., were planted as two-year-old seedlings (total $n = 96$; 24 replicates per species per plot) arranged in two rows. Plant growth was monitored over five months, from May to October 2024. A total of 26 soil samples were collected before planting, 28 soil samples after planting, 16 plant samples before planting, and 36 plant samples after planting.

Table 1.

Sampling Framework for Soil and Plant Samples

	Date	Sites	Soil Depth	Reps/ Site	Total Reps	Purpose	Total
Soil samples	2024.05.11	2	Topsoil (0–10 cm)	2	4	Before planting	26
		2	Subsoil (10–30 cm)	2	4		
	2024.10.02	2	Topsoil (0–10 cm)	2	4	After planting	
		2	Subsoil (10–30 cm)	4	8		
		1	Topsoil	2	2	Natural vegetation soil	
		1	Subsoil	4	4		
Plant samples	2024.05.11	2	Aboveground (stem, leaves)	1	2	Before planting seedlings	16
		2	Underground (roots)	1	2		
	2024.10.02	3	Aboveground (stem, leaves)	2	6	From two sites and natural plants	
		3	Underground (roots)	2	6		

Soil and Plant Sampling

Soil was sampled using a stainless-steel auger, sealed in labeled polyethylene bags, and transported under cool conditions. Plant tissues were washed with deionized water, air-dried at ambient temperature, and stored in paper envelopes.

Heavy Metal Analysis

Laboratory analyses were conducted at KhanLab Mineral Analysis Laboratory in Ulaanbaatar, Mongolia. Samples were digested using a microwave-assisted acid digestion protocol in accordance with USEPA Method 3051A [14]. The concentrations of 28 heavy metals, including As, Cd, Pb, Cr, and Ni, were determined using inductively coupled plasma mass spectrometry (ICP-MS). Quality assurance and quality control procedures included the analysis of method blanks, sample duplicates, and certified reference materials in each analytical batch, following standard protocols for environmental heavy metal analysis [15], [16]. Duplicate soil samples were collected from each experimental plot and averaged.

Results

To initiate the phytoremediation experiment, a designated area at the tailing's storage facility was fenced off to minimize disturbance and ensure experimental integrity. Seedlings of *Reaumuria soongorica* and *Nitraria sibirica* were transplanted and monitored over five months for their capacity to reduce heavy metal concentrations in the soil. Below Figure 1 illustrates the preparation of the research site, including the fencing process and the planting of seedlings.

Figure 1. Fencing of the research site and the process of seedling planting

The comparison of heavy metal concentrations in soil samples collected from the tailings storage facility (TSF) of the Oyu Tolgoi Mine and nearby control sites revealed notable contamination patterns, particularly for arsenic (As). Arsenic concentrations in both the tailings and control soils consistently exceeded the permissible limits set by the Mongolian National Standard MNS 5850:2019, indicating widespread arsenic contamination in the study area.

Initial soil analyses from May 11, 2024, showed arsenic concentrations ranging from 13.89 to 14.50 mg/kg in the tailings soil and slightly lower but comparable levels of 12.38 to 12.51 mg/kg at the control site. After five months, arsenic levels increased significantly to between 22.40 and 26.22 mg/kg in the tailings soil and 24.04 to 25.72 mg/kg in the control soil, indicating ongoing arsenic mobilization or accumulation (Table 2).

Other heavy metals, such as chromium (Cr), nickel (Ni), and lead (Pb), were also detected at considerable levels. Chromium (Cr) increased from 26.01–30.47 mg/kg in May to 36.56–42.98 mg/kg in October in the tailings soil, while control soil chromium levels fluctuated between 26.31 and 49.59 mg/kg. Nickel (Ni) concentrations rose from approximately 11 mg/kg to over 17 mg/kg in the tailings soil with similar trends in the control. Lead (Pb) levels remained relatively stable, ranging between approximately 16.7 and 23.3 mg/kg during the study period (Table 2).

Table 2

Concentrations of Heavy Metals (mg/kg) in Tailings and Control Soils at Oyu Tolgoi Site

Heavy Metals (mg/kg)	As	Cd	Co	Cr	Cu	Mo	Ni	Pb	Sr	V	Zn
Tailings soil 05/11 (rep 1)	13.89	<1	11.45	30.47	24.55	<5	11.02	21.87	299.7	62.49	72.77
Tailings soil 05/11 (rep 2)	14.50	<1	10.99	26.01	31.80	<5	11.05	16.67	246.9	59.80	94.44
Tailings soil 10/02 (rep 1)	22.40	<1	10.65	36.56	24.72	<5	16.40	23.29	241.6	65.46	122.6
Tailings soil 10/02 (rep 2)	26.22	<1	13.38	42.98	32.09	<5	17.49	19.95	395.8	80.99	94.39
Control soil 05/11 (rep 1)	12.38	<1	10.07	26.31	36.50	<5	13.61	19.28	197.1	54.27	101.6

Control soil 05/11 (rep 2)	12.51	<1	11.94	30.63	88.35	<5	11.09	20.35	252.9	67.80	93.07
Control soil 10/02 (rep 1)	24.04	<1	14.63	49.59	37.20	<5	22.11	16.76	343.0	93.77	82.84
Control soil 10/02 (rep 2)	25.72	<1	12.58	32.19	31.28	<5	18.16	16.72	329.1	78.57	79.62

To provide environmental context, soil contamination thresholds established by the Mongolian National Standard MNS 5850:2019 are presented in Table 3 alongside data from a regional soil quality survey encompassing 506 samples from the Gobi region.

The average concentrations of heavy metals such as arsenic (15.2 mg/kg), cobalt (9.8 mg/kg), and chromium (30.8 mg/kg), in uncontaminated soils, remained below the defined permissible levels. However, arsenic levels detected in the current study exceeded the 20 mg/kg permissible threshold at multiple sampling points, underscoring a significant concern regarding localized arsenic contamination.

Table 3

Reference Thresholds and Regional Baseline Concentrations of Heavy Metals in Gobi Region Soils Based on MNS 5850:2019

Heavy Element	**As**	**Cd**	**Co**	**Cr**	**Cu**	**Mo**	**Ni**	**Pb**	**Sr**	**V**	**Zn**
Average natural uncontaminated soil (mg/kg)	15.2	0.0	9.8	30.8	16.3	3.0	16.3	21.1	269.0	63.0	60.3
Permissible level (MNS 5850:2019)	20	3	50	150	100	5	150	100	800	150	300
Toxic level (MNS 5850:2019)	50	10	500	400	500	20	1000	500	3000	600	600
Dangerous level (MNS 5850:2019)	100	20	1000	1500	1000	50	1800	1200	6000	1000	1000

The phytoremediation experiment demonstrated that native shrub species *Reaumuria soongorica* (Pall.) Maxim. and *Nitraria sibirica* Pall., when planted as two-year-old seedlings in the contaminated soil, contributed to significant reductions in heavy metal content. *Reaumuria soongorica* showed higher uptake efficiency, reducing heavy metal concentrations by 65.4–82.7% across roots, stems, and leaves compared to 14.8–75.4% observed for *Nitraria sibirica*.

Figure 2 displays the concentrations of four heavy metals: arsenic (As), chromium (Cr), nickel (Ni), and lead (Pb) in soil samples from the tailings site and control site, measured before (May 11) and after (October 2) planting.

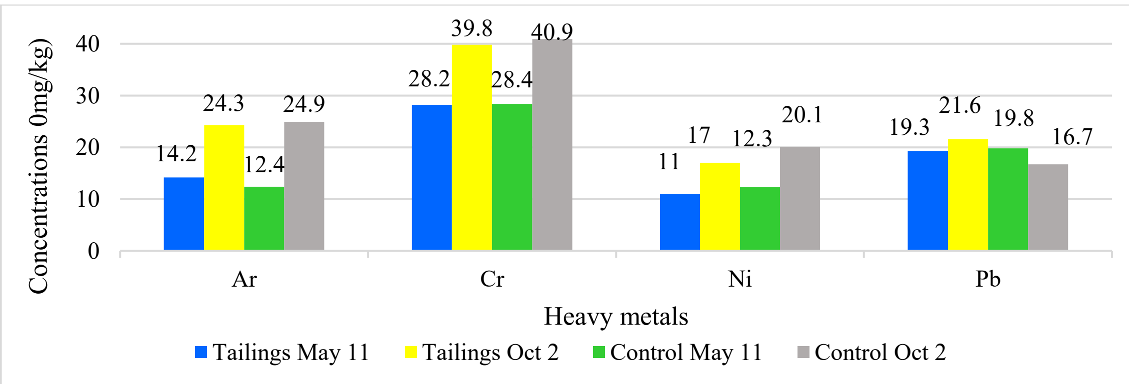

Figure 2. The concentrations of arsenic (As), chromium (Cr), nickel (Ni), and lead (Pb) in soil samples collected from the tailings site and control site before (May 11) and after (October 2) planting.

Arsenic (As) concentrations increased at both sites over time, with October values higher than May values. Notably, arsenic levels exceeded the Mongolian standard (20 mg/kg) after five months, especially in the control site. This indicated widespread contamination, possibly from natural sources or dust transport.

Chromium (Cr) levels showed the most significant increase, especially in the control site, which recorded the highest concentration overall (~41 mg/kg in October). Both sites exceeded typical background levels (~30.8 mg/kg), but remained under the national permissible limit (150 mg/kg).

Nickel (Ni): Ni concentrations rose from May to October at both sites, with the control site showing a slightly higher final value. Though still below permissible thresholds, the increasing trend highlights possible mobility of Ni in arid soil conditions.

Lead (Pb) levels fluctuated modestly and remained relatively stable, with minor increases at the tailings site and slight decreases at the control site between May and October. All values stayed below the permissible limit (100 mg/kg), but remained elevated compared to background values (~21.1 mg/kg).

Figure 3 shows the heavy metal uptake efficiency (in percentage) of two native desert plant species—*Reaumuria soongorica* (green solid line) and *Nitraria sibirica* (blue dashed line)—after five months of growth in contaminated soil at a mine tailings site.

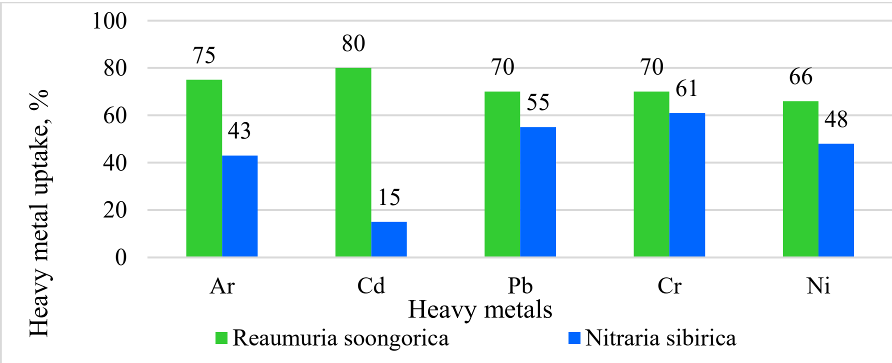

Figure 3. A line graph illustrating the percentage uptake of key heavy metals (As, Cd, Pb, Cr, Ni) by Reaumuria soongorica and Nitraria sibirica after five months of growth in contaminated soils.

Reaumuria soongorica demonstrated consistently higher metal uptake efficiency, especially for cadmium and arsenic, absorbing: ~75% of arsenic (As), over 80% of cadmium (Cd), nearly 70% of lead (Pb), ~70% of chromium (Cr), and ~66% of nickel (Ni). While Nitraria sibirica showed more variable and generally lower uptake, with only ~15% uptake of Cd (lowest), ~43% for As, ~55% for Pb, ~61% for Cr (highest among its data), and ~48% for Ni.

Figure 4 presents a boxplot of arsenic (As) concentrations in soil samples collected from both the tailings site and control site at two time points: May (before planting) and October (after five months).

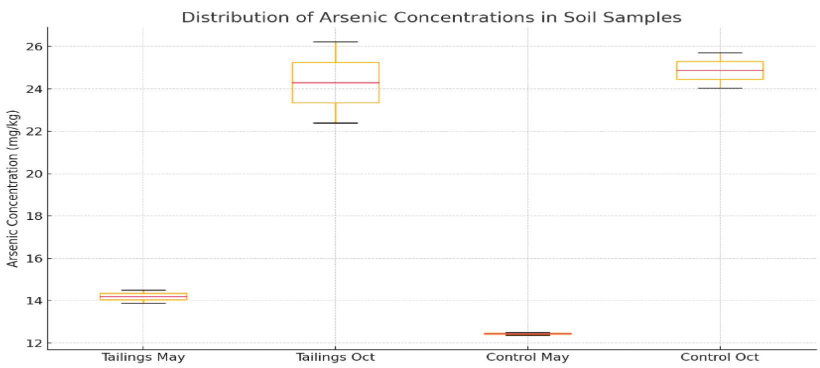

Figure 4. Box plots showing the distribution of arsenic concentrations in soil samples from the tailings and control sites, before (May) and after (October) planting. The data highlight the increase and variability in arsenic levels over time at both sites.

In Tailings Site, in May, arsenic levels were relatively low and tightly clustered (~14 mg/kg), below the Mongolian permissible limit (20 mg/kg, MNS 5850:2019). By October, a significant increase in concentration was observed (median ~24.5 mg/kg), exceeding the permissible threshold and showing greater variability. This suggests a progressive accumulation or mobilization of arsenic at the tailings site over time. While in the Control Site, the control samples also showed a rise in arsenic from ~12.5 mg/kg in May to ~25 mg/kg in October—an unexpected increase in a supposedly less-affected area, also exceeding the permissible level. This could indicate regional arsenic mobility through wind, water runoff, or deep soil processes affecting both sites.

Discussion

Phytoremediation has increasingly been recognized as an environmentally friendly, cost-effective, and sustainable approach for mitigating heavy metal contamination in soils and groundwater. It relies on plants with specific physiological and biochemical traits capable of absorbing, accumulating, detoxifying, or stabilizing heavy metals within contaminated substrates [10], [11]. In arid mining environments such as the Gobi region, phytoremediation provides several ecological and socioeconomic benefits, including the stabilization of contaminated soils, reduction of metal bioavailability, and restoration of ecosystem functions. The use of native halophytic and drought-tolerant species is particularly advantageous, as these plants are naturally adapted to harsh climatic conditions, saline soils, and low nutrient availability, offering a sustainable and socially acceptable alternative to chemical or physical remediation methods.

The analysis of heavy metals in soil samples from the Oyu Tolgoi tailings storage facility (TSF) and adjacent control areas revealed that arsenic (As) is the primary contaminant of concern. During the five-month monitoring period, arsenic concentrations at both sites consistently exceeded the Mongolian National Standard (MNS 5850:2019; 20 mg/kg), ranging from 22.40–26.22 mg/kg at the TSF and 24.04–25.72 mg/kg at the control sites. This temporal increase suggests that arsenic contamination may result from mining-related leaching from tailings, but it could also be influenced by natural geochemical processes occurring in the Gobi Desert. [18]. Elevated arsenic levels are of critical concern due to their toxicity, mobility, and bioaccumulation potential, posing risks to soil quality, groundwater, and ultimately human and ecological health.

Other heavy metals, including chromium (Cr), nickel (Ni), and lead (Pb), were present at elevated but sub-toxic levels relative to national standards. Chromium concentrations increased moderately from 26–30 mg/kg to 36–43 mg/kg in tailings soils and up to 50 mg/kg at control sites, remaining below the permissible limit of 150 mg/kg [18]. Nickel concentrations also rose slightly from 11 to over 17 mg/kg, while lead remained between 16.7 and 23.3 mg/kg, both below critical thresholds. These patterns indicate detectable enrichment related to mining activities but no immediate risk of acute toxicity. Concentrations of cadmium (Cd), molybdenum (Mo), and cobalt (Co) were below detection limits or within permissible ranges, while zinc (Zn) and copper (Cu) showed minor variability consistent with regional soil background levels. Collectively, these results suggest that the contamination profile is dominated by arsenic, with localized enrichment of other metals possibly influenced by tailings leachate, atmospheric deposition, or limited microbial activity under arid conditions.

The phytoremediation component of this study demonstrated the promising potential of native halophytic plants *Reaumuria soongorica* (Pall.) Maxim. and *Nitraria sibirica* Pall. for mitigating soil heavy metal contamination. Both species are widely distributed across Mongolia's arid and semi-arid landscapes and have demonstrated strong tolerance to drought, salinity, and nutrient-poor soils. The experimental results indicate that *R. soongorica* exhibited superior metal uptake efficiency, removing between 65.4% and 82.7% of major toxic metals (As, Cd, Pb, Cr, Ni), compared to *N. sibirica*, which achieved 14.8%–75.4%. The particularly high cadmium uptake (~82%) by *R. soongorica* is notable, given Cd's toxicity and mobility in soil systems. These findings align with reports by Liao et al. [19], who identified both species as pioneer plants capable of tolerating and accumulating heavy metals in mining-impacted deserts of northwestern China. The higher accumulation observed in *R. soongorica* may be attributed to species-specific physiological or biochemical mechanisms of the plant.

While these findings highlight the feasibility of phytoremediation for Gobi mining environments, challenges remain for large-scale implementation. The long-term success of phytoremediation in arid ecosystems also depends on climatic variability, soil characteristics, and plant resilience under extreme stressors. In summary, this study contributes valuable insight into the dynamics of heavy metal contamination and demonstrates the remediation potential of native halophytes in the arid mining landscapes of the Gobi. The consistent detection of elevated arsenic levels underscores the need for continuous monitoring and adaptive management strategies. Phytoremediation represents a viable, sustainable pathway toward rehabilitating Mongolia's mining-impacted ecosystems

Conclusion

This study identified arsenic contamination in soils at the Oyu Tolgoi tailings facility and control sites, with concentrations exceeding Mongolian permissible limits and increasing over five months. Other heavy metals were elevated but remained below toxic thresholds.

The native plants *Reaumuria soongorica* and *Nitraria sibirica* demonstrated significant capacity to reduce soil heavy metal levels, with *Reaumuria soongorica* showing particularly higher uptake.

These findings support the potential of these species for phytoremediation in arid mining regions, offering a sustainable approach to mitigate soil heavy metal pollution.

Conflict of Interests:

The authors declare no conflict of interests.

Author's Contribution:

B.E. conducted field work, analyzed data, and wrote original draft preparation. A.P designed the oncept of this study, analyzed data, validated, B.B. revised, reviewed, and edited. All authors read and approved the final manuscript.

Acknowledgements:

We sincerely thank our colleagues at Green Green NGO for their invaluable support and for providing the opportunity to conduct this research. Their collaboration and encouragement were essential to the successful completion of this study.

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