



Unseen Threats: Soil Pollution from Household Ash in Nalaikh's Ger Districts

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ABSTRACT

Rapid urban expansion, poor waste management practices, and a reliance on coal-based energy sources have contributed significantly to soil pollution in Mongolia's urban ger districts. This study investigates the environmental risks posed by ash disposal from household coal burning in the Nalaikh district of Ulaanbaatar, focusing on heavy metal pollution of soils. Nalaikh, a historically important coal mining region located 35 km east of Ulaanbaatar, faces a unique combination of legacy mining impacts and growing residential pressure, particularly in the ger settlements that house approximately 75% of the district's population.

During the winter months, households in ger districts typically burn 25 kg of coal daily, producing around 5kg of ash per day. Due to limited municipal waste services, this ash is often stored on private land or temporarily dumped in surrounding areas. The ash contains high concentrations of hazardous substances, including heavy metals such as Pb, Zn, Cu, and As, which can migrate into the soil and pose significant health and environmental risks.

This study employed a multi-method approach to assess the extent of soil pollution from ash. A total of 45 samples (surface soil, soil-ash mixtures, and pure ash) were collected from 15 locations across the district. The samples were analyzed using portable X-ray fluorescence (pXRF) and Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). Results revealed elevated concentrations of heavy metals, with some ash samples showing lead (Pb) levels of up to 2950 mg/kg, nearly 50 times higher than the national soil quality standards. Spatial analysis showed pollution hotspots near informal ash dumps, former mining sites, and household heating zones.

In addition to the laboratory analysis, a household survey was conducted to collect data on coal use patterns, ash management practices, and awareness of environmental impacts. The findings highlight both the scale of the problem and the lack of public awareness and infrastructure for safe ash disposal.

The study underscores the urgent need for improved solid waste management strategies in Mongolia's ger districts, including the introduction of safer fuel alternatives, targeted soil remediation efforts, and policy interventions that support sustainable waste handling in residential areas. The results contribute to the broader discourse on green development and circular economy by identifying opportunities for recycling and resource recovery from household ash, while informing evidence-based policy to mitigate environmental and public health risks in urban Mongolia.

Keywords: Coal ash, Ger districts, Soil contamination, Heavy metals.

1. Introduction

1.1 State of the art

Mongolia's rapid urbanization, particularly in Ulaanbaatar has created significant environmental and public health challenges, especially in informal residential areas known as ger districts. Over 60% of the city's population resides in these districts (NSO, 2024), where access to essential public infrastructure such as piped water, centralized sewage systems, and regular waste collection remains inadequate or entirely absent. In the

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absence of alternative heating options, households primarily rely on coal and semi-coke briquettes to endure the long, harsh winters.

A single household can burn up to 25 kg of coal per day during winter, producing approximately 5–6 kg of ash daily (Battsengel et al., 2020). With limited waste management services, most households store ash within their yards or dispose of it informally dumping it in open spaces or spreading it on unpaved roads. These practices contribute to localized air and soil pollution and facilitate the dispersal of heavy metals into the surrounding environment.

Mongolian coal deposits vary regionally, becoming younger from west to east and ranging in rank from high-rank bituminous in the west to lignite in the east. This variation directly affects the ash content and composition produced during combustion. Petrographic studies show that Mongolian coals are humic in type, with vitrinite contents ranging from 44.9–96.6 vol.% depending on age and location, inertinite from 15–53.3 vol.%, and liptinite under 11.7 vol.%. These characteristics influence ash formation and the potential environmental hazards of coal combustion (Erdenetsogt et al., 2009).

Coal fly ash and bottom ash are primarily composed of oxides such as SiO_2 , Al_2O_3 , Fe_2O_3 , TiO_2 , and CaO , along with trace heavy metals including As, Pb, Zn, Ni, Cu, Mn, Cd, Cr, and Se, which can pose environmental and health risks if leached under certain conditions (Jayaranjan and Annachhatre, 2014).

Despite the scale of the issue, coal ash disposal in ger districts remains understudied and poorly regulated. Municipal waste collection systems primarily focus on landfill transport without prior sorting or contamination control, leaving large quantities of ash and mixed waste unmanaged. Households often include ash in general waste or leave it untreated on their premises, leading to hazardous substance accumulation in the soil and potential contamination of groundwater sources.

Environmental studies have confirmed elevated concentrations of toxic elements including Pb, Zn, Mo, Cr, Cu, Cd, Ni, Co, Sr, As, and Hg in Ulaanbaatar's urban soils, particularly in low-income ger areas where domestic coal burning is common (Kasimov et al., 2011; Chung and Chon, 2014). One study specifically attributed moderate mercury contamination to coal combustion. The spread of these pollutants correlates with the expansion of informal settlements, where unregulated growth and inadequate services increase community vulnerability (Bilguun et al., 2020).

In Ulaanbaatar, winter air pollution from small coal- and wood-fired stoves contributes significantly to particulate matter (PM) emissions, which contain toxic trace elements such as Al, As, B, Bi, Cd, Cr, Cu, Ni, Mo, Pb, S, Tl, U, and Zn. Many of these exceed local soil standards and pose environmental and public health risks. Pilot tests of locally developed low-cost electrostatic precipitators (ESPs) demonstrated the potential to reduce PM emissions by 10–50%. However, while ESPs effectively remove pollutants from the air, safe disposal strategies for the collected fly ash are essential to prevent soil and water contamination and the bioaccumulation of toxic elements (Karthé et al., 2020).

Residents of ger districts are especially at risk due to their proximity to pollution sources, limited awareness of waste-related health hazards, and lack of access to environmental and healthcare services. Many are unaware of coal ash toxicity. Households often store ash for weeks within fenced yards, allowing its dispersion into the soil and air. Children, unaware of the risks, may play in ash deposits as if they were ordinary soil. Despite public campaigns and the 2019 ban on raw coal in Ulaanbaatar replaced with refined fuel briquettes, the environmental risks associated with ash have received little regulatory attention. Existing environmental monitoring frameworks rarely address residential soil contamination, and there are virtually no localized guidelines for the safe disposal or reuse of coal ash.

These environmental risks are directly linked to public health outcomes. In 2020, over 120 children and 1,250 adults reportedly died from pneumonia a rise of more than 8,700 cases compared to 2015 (Battsengel et al., 2020). While multiple factors contribute to such health impacts, exposure to contaminated air, soil, and water from improper ash disposal is likely a contributing factor. Compounding the issue, many residents lack access to information about heavy metal exposure and safe ash handling practices.

Although Mongolia's Law on Waste (2017) and other environmental regulations contain general provisions for pollution control, enforcement in informal settlements remains weak. Specific guidelines for the safe disposal, reuse, or neutralization of household ash are absent. Consequently, harmful practices such as open burning, burying, or spreading ash continue unchecked, underscoring systemic gaps in policy, governance, and

public awareness.

This study aims to fill existing knowledge gaps by investigating heavy metal contamination in the soils of Nalaikh district, focusing on selected ger areas located centrally, remotely, and near landfills and industrial sites. A total of 45 samples, comprising soil, ash-soil mixtures, and pure ash were analyzed to assess contaminant concentrations and their spatial distribution. Concurrently, household-level surveys will explore public awareness, waste disposal behaviors, and key factors influencing ash management practices. By integrating scientific analysis with social data, the research will support the development of practical and policy-relevant strategies for soil and waste management. Furthermore, it will contribute to Mongolia's broader efforts to enhance environmental health, promote sustainable urban development, and advance circular economy principles.

1.2 Study sites

This study focuses on the Nalaikh district, located approximately 35 kilometers east of Ulaanbaatar, the capital of Mongolia. Administratively, it is divided into eight subdistricts, or *khoroos* (Fig. 1), *Khoroos 5* and *6* are partly located within the Gorkhi-Terelj National Park, a well-known natural attraction. Nalaikh has a population of around 39,000 residents, with approximately 75% living in ger areas (NSO, 2024). Historically, it is notable as the site of Mongolia's first state-operated coal mine, established in 1922. While this industrial legacy contributed significantly to the region's early economic development, it has also left lasting environmental consequences.

In recent decades, Nalaikh has undergone rapid population growth and urban expansion, particularly in its ger districts. These areas are often characterized by unregulated land use, informal housing, and limited access to basic infrastructure and public services. As a result, the district faces a complex mix of environmental pressures, including residual contamination from historical mining, the continued use of coal for residential heating, and an inadequate solid waste management system. Nalaikh district lies within the forest-steppe zone, where average winter temperatures range from -20°C to -25°C and summer temperatures from $+23^{\circ}\text{C}$ to $+26^{\circ}\text{C}$ (NAMEM). Geologically, the Nalaikh Depression has a complex formation history, with thick sandstones, granite intrusions, and Quaternary sediments forming the basis for steppe soils and discontinuous permafrost. The harsh continental climate, characterized by low precipitation and strong seasonal contrasts, further influences soil and water dynamics. Human activities such as coal mining, industrial operations, and widespread ger settlements have caused significant surface disturbance, waste accumulation, and long-term environmental stress (Nottebaum et al., 2020). Moreover, pollutants and coal ash are redistributed by prevailing winds, dispersing contaminants southeastward from the city, power plant, and mining areas into surrounding ecosystems (Knippertz & Sodnomdarjaa, 2024).

Following a government ban on raw coal in September 2022, households transitioned to using processed coal briquettes for heating. While this shift aimed to reduce air pollution, it has not fully addressed environmental concerns. For the approximately 6,000 households in Nalaikh, an estimated 5,000 to 7,000 tons of ash is generated each winter heating season. Due to the lack of proper ash disposal systems, much of this waste is either stored on household plots or informally dumped into nearby abandoned open-pit mining areas, often located just 100 to 300 meters from residential zones. Waste collection services are irregular, with ash collection typically occurring only once every two to four weeks, further exacerbating the risk of soil contamination and environmental degradation.

Fig. 1 Study sites: Nalaikh district, its subdistricts (locations of landfilling areas and soil samplings)

2. Data and Methods

2.1 Field sampling

A total of 45 environmental samples were collected from 15 distinct sampling points distributed across the selected *khoroos*. Sampling sites were chosen based on residential density patterns and dominant wind directions, which influence the spatial dispersion of ash particulates.

Each sampling point included three types of samples collected from each household:

- Surface soil (0–15 cm depth), representing the natural topsoil in the yard;
- Ash-soil mixtures from waste storage areas within the fenced yard;
- Pure ash samples from deposits in the same waste storage in the yard.

Approximately 200–300 grams of material were collected from each sample type per location, placed in clean polyethylene bags, labelled, and transported to the laboratory for further analysis. The sampling locations are illustrated in Figure 1.

2.2 Laboratory analysis

Collected samples were analyzed to determine the concentration of key heavy metals, along with supporting physical and chemical soil parameters. Laboratory work was conducted in both the German-Mongolian Institute for Resources and Technology (GMIT) laboratory and SGS Mongolia laboratory, employing complementary analytical methods for accuracy and validation.

2.2.1 Sample preparation and on-site analysis (GMIT Laboratory)

- All samples were air-dried at room temperature for approximately 48 hours to remove moisture content.
- Dried soil samples were sieved through a 2 mm mesh to remove large debris and homogenize the material. The sieved samples were then pulverized to a particle size of up to 0.6 micrometres.
- Representative subsamples were prepared for heavy metal and soil property analysis.
- A handheld X-Ray Fluorescence (XRF) spectrometer was used for preliminary quantification of heavy metals including lead (Pb), zinc (Zn), copper (Cu), chromium (Cr), nickel (Ni), strontium (Sr), and arsenic (As).

2.2.2 Confirmatory elemental analysis (SGS Mongolia Laboratory)

To ensure data quality and precision, 26 selected samples were sent for confirmatory testing using Inductively Coupled Plasma–Optical Emission Spectroscopy (ICP-OES) at SGS Mongolia Laboratory, an internationally accredited facility. ICP-OES is a highly sensitive and accurate analytical method widely used for quantifying elemental concentrations in environmental matrices. This method provides detailed compositional data for the evaluation of heavy metal contamination in both soil and ash samples.

2.3 Household questionnaire survey

To complement the physical sampling, a structured questionnaire was conducted with 14 households (about one-third of the sampling sites) to capture information on fuel use, ash disposal practices, environmental awareness, and health perceptions. Participants were selected based on proximity to sampling points and willingness to participate. The questionnaire included 20 questions across four sections: household energy use, ash disposal practices, perceptions of environmental risk, and awareness and attitudes.

2.4 Pollution assessment

To quantitatively assess the degree of heavy metal contamination in soils affected by household ash disposal, the Geoaccumulation Index (Igeo) was employed. This index provides a standardized method for evaluating contamination by comparing measured elemental concentrations against natural background levels, while accounting for inherent geological variability. The formula for calculating the Geoaccumulation Index is expressed as:

where:

- C_n represents the measured concentration of element n in the soil sample,
- B_n is the geochemical background concentration of element n , typically derived from uncontaminated reference soils in the region,

- The factor 1.5 is a correction coefficient that compensates for natural fluctuations in the background levels due to lithological heterogeneity and minor anthropogenic influences.

The Igeo values are classified into seven contamination categories ranging from uncontaminated ($I_{geo} \leq 0$) to extremely contaminated ($I_{geo} > 5$), providing a clear framework for interpreting environmental pollution severity (Müller, 1969). This metric was calculated for each target heavy metal (Pb, Zn, Cu, As) across all soil and ash samples to map spatial contamination patterns and identify critical pollution hotspots within Nalaikh's ger areas.

3. Results and Discussion

The results obtained from both pXRF and ICP-OES analyses showed generally similar results detecting heavy metal concentrations in the sampled materials (Fig. 2).

Both analytical approaches revealed notably elevated concentrations of heavy metals (HMs) in household ash samples collected from informal disposal areas across the Nalaikh district. Specifically, lead (Pb) concentrations averaged 145 mg/kg, zinc (Zn) reached 210 mg/kg, and copper (Cu) was measured at approximately 135 mg/kg. These values are considerably higher than typical background levels and can be attributed to the widespread use of low-grade coal and compressed briquettes for domestic heating in ger districts. These fuels often contain trace elements that remain in the ash following combustion.

The presence of such high concentrations of heavy metals in the ash suggests that continuous disposal of combustion by products directly onto open ground is likely contributing to long-term soil contamination and ecological degradation. The metal residues in ash are often fine-grained and easily dispersed by wind or water, further exacerbating the spread of contaminants in the surrounding environment. Additionally, these findings reinforce concerns regarding human exposure risks, especially in residential areas where children play and households maintain vegetable gardens in contaminated soil.

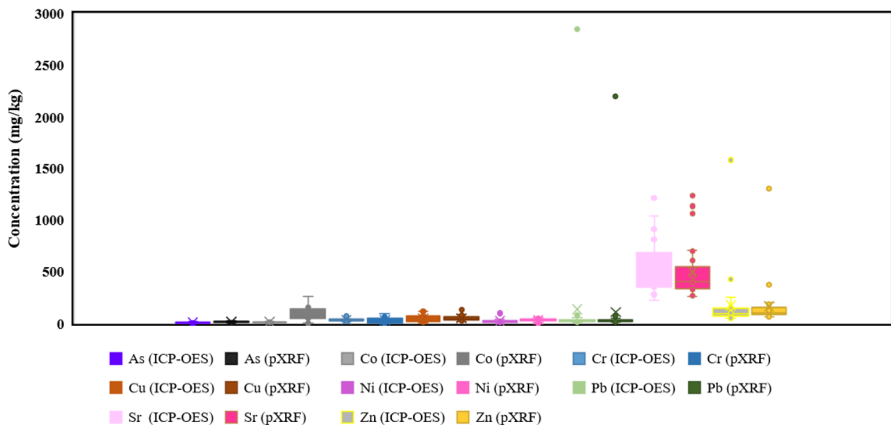


Fig. 2 HMs concentrations by ICP-OES and pXRF

Soil samples collected from informal ash disposal sites also exhibited significantly elevated concentrations of heavy metals, mirroring the high contamination levels observed in the ash itself. In numerous cases, the measured concentrations of metals such as lead (Pb), zinc (Zn), and copper (Cu) exceeded the national soil quality standards of Mongolia, which are established to safeguard public health and ensure environmental sustainability. Among the analyzed samples, the highest concentration of lead (Pb) was recorded at sampling point 15, located near a local thermal power plant. Here, Pb levels ranged between 2800–2950 mg/kg, which is approximately 50 times greater than the permissible limit outlined in the Mongolian soil quality guidelines (Fig. 3). Such extreme values strongly indicate not only the direct contamination from ash but also the possibility of long-term heavy metal accumulation in the soil.

These findings underscore the severe environmental implications of unregulated ash dumping practices, particularly in urban fringe and ger districts where coal-based heating remains the dominant source of energy during winter months. The elevated metal content in soils adjacent to ash disposal areas suggests that toxic substances from the ash are migrating into the surrounding environment, either through surface runoff, leaching, or wind-driven dispersion of fine ash particles. Over time, this process can lead to bioaccumulation of hazardous elements in local vegetation, contamination of shallow groundwater resources, and chronic exposure risks for residents, especially vulnerable groups such as children and the elderly. Furthermore, the issue is exacerbated in areas with poorly managed waste systems and high population density, where informal ash dumping occurs frequently and without oversight. Residents in these zones are often unaware of the long-term consequences of ash disposal near homes, schools, and community spaces. This situation emphasizes the urgent need for comprehensive public awareness programs, effective regulatory enforcement, and the development of sustainable waste management infrastructure to reduce environmental health risks and prevent further soil degradation in Mongolia's rapidly expanding peri-urban areas.

The results of this study clearly demonstrate that coal ash has a significant negative impact on soil quality, particularly through the elevation of heavy metal concentrations. This is supported by the average concentration values of soil, ash, and soil-ash mixture samples collected across the study area. A comparative analysis, as illustrated in Figure 4, highlights the clear trend of increasing contamination where coal ash is present. Specifically, ash samples alone exhibited the highest concentrations of heavy metals, reflecting the residual pollutants from the combustion of low-grade coal and briquettes commonly used in household heating. When mixed with soil whether through direct disposal or gradual deposition over time these ash particles significantly alter the chemical composition of the soil. The data show that the concentration of heavy metals in soil-ash mixture samples increased by approximately 1.5 to 2.3 times compared to uncontaminated surface soil samples.

This increase is particularly concerning in urban ger areas, where informal and unregulated ash dumping is a widespread practice due to limited waste disposal infrastructure. Over time, the mixing of ash into surface soil not only reduces soil fertility and alters its structure but also introduces persistent and potentially toxic metals such as Pb, Zn, Cu, and As. These contaminants can accumulate in the topsoil layer, where they pose risks to both human and ecological health.

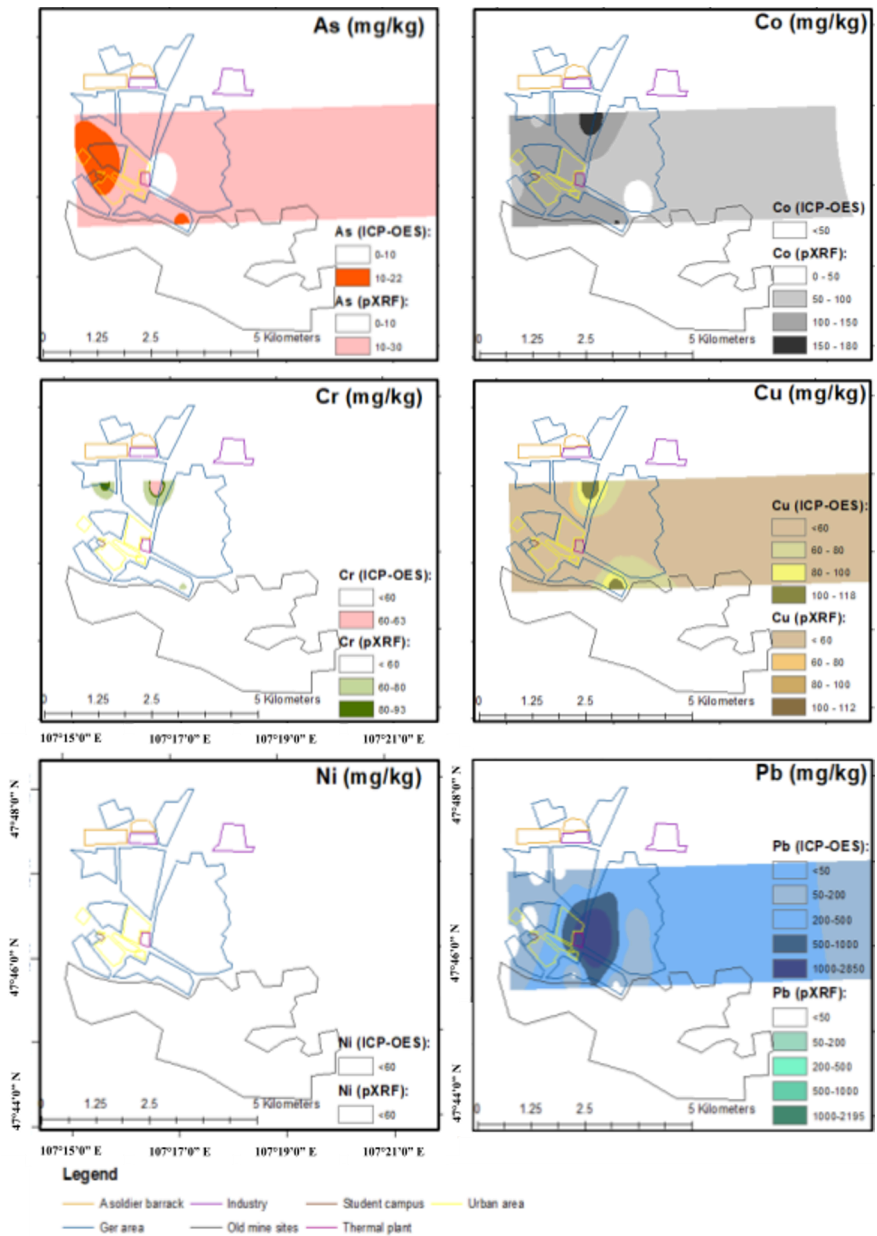


Fig. 3 Spatial distributions HMs concentrations are compared with MPL of (MNS5850:2019)

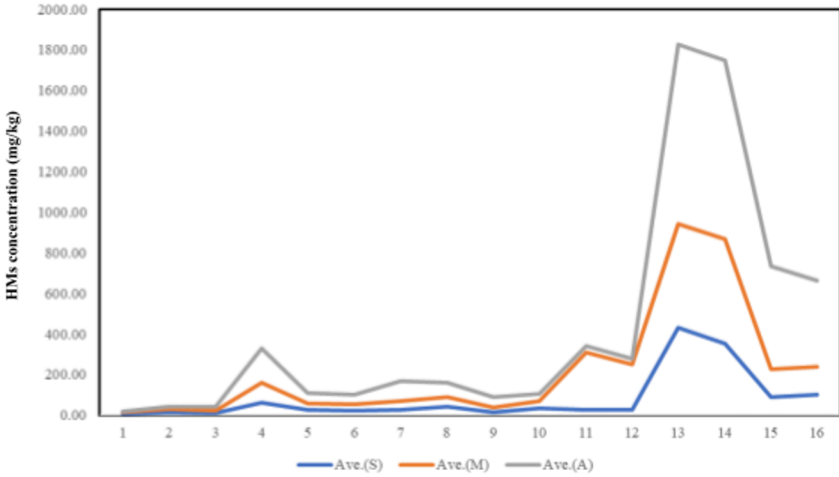


Fig. 4 Average concentrations of HMs (mg/kg) in Soil (S), Mixed soil and ash (M), and Ash (A)

Based on the results of the Geoaccumulation Index (Igeo) analysis and the spatial distribution mapping of heavy metals, moderate to extremely high pollution levels were observed for several key pollutants, particularly Pb, Co, Cr, and Zn (Fig. 5). These elevated levels were most prominent in households located near landfill sites and the thermal power plant, which are areas of high environmental vulnerability due to their role as potential sources of pollution.

This spatial trend is further supported by the clustering of high Igeo values around these hotspots, which implies the migration and deposition of contaminants via wind dispersal, surface runoff, or direct dumping. Given the prevailing wind directions in the study area and the topographic features that may facilitate pollutant movement, these external sources could significantly influence local soil contamination patterns.

Moreover, the presence of such contamination in residential areas raises important concerns regarding long-term human exposure, especially among vulnerable populations such as children, and possible ecological impacts on urban vegetation and nearby water sources. These findings underscore the need for site-specific environmental assessments, remediation strategies, and the development of clear policy interventions aimed at controlling emissions, managing solid waste more effectively, and enforcing buffer zones around pollution-prone facilities.

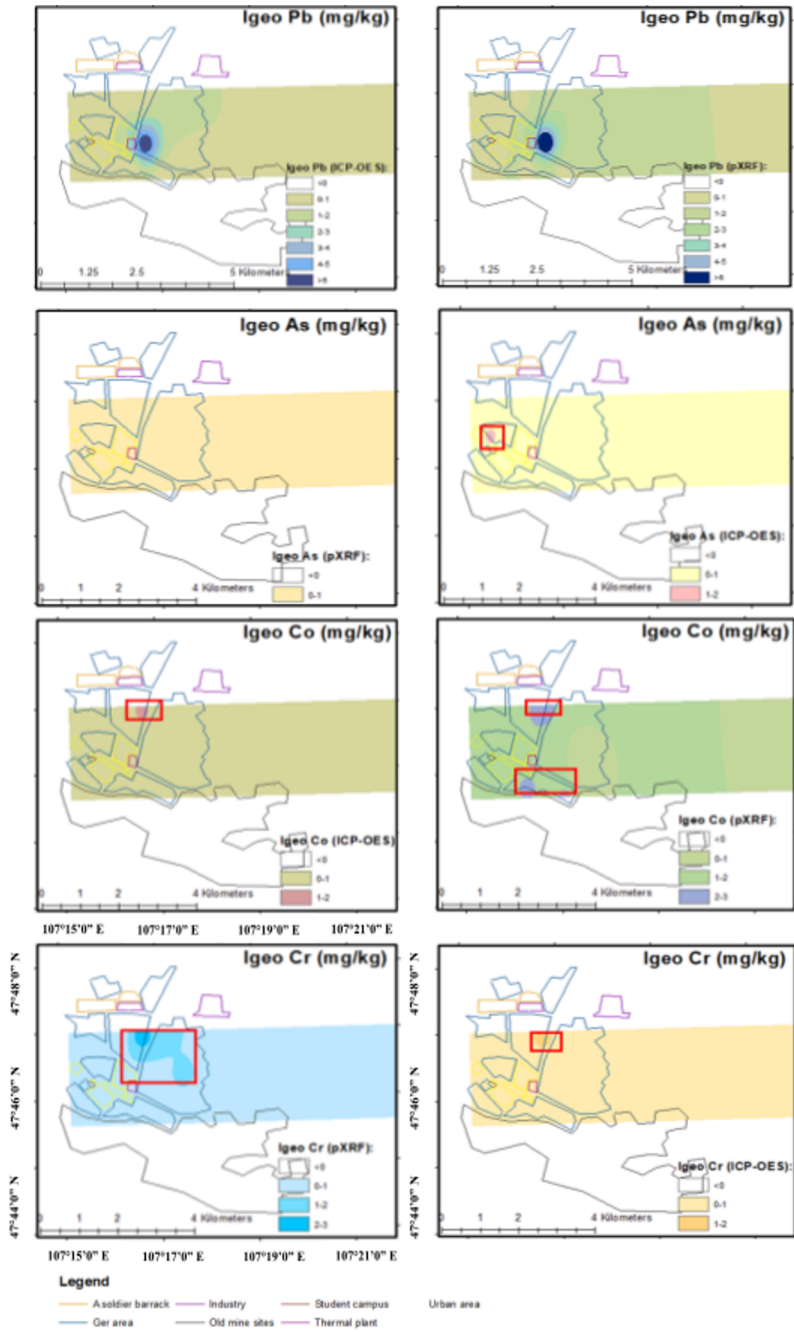


Fig. 5 Spatial distributions of Igeo (<0 no poll; 0-1 no to mode poll; 1-2 mode poll; 2-3 mode to high poll; 3-4 high poll; 4-5 high to extr poll; >5 extr poll)

Regarding to the survey results shows that residents reported living in the area for an average of 11 years, indicating prolonged exposure to potential soil contaminants. The survey results identified the general types of household waste (Fig. 6), daily ash generation during winter, and the types of ash storage methods used (Fig. 7). All participating households used coal briquettes in traditional stoves, producing an average of up to 7 kg of ash daily. Due to insufficient waste collection services, ash was often stored in metal bins within household fences for extended periods, increasing the risk of soil contamination through wind dispersal and surface runoff.

Although briquette use has helped reduce air pollution in winter, the lack of proper ash disposal has contributed to localized soil pollution.

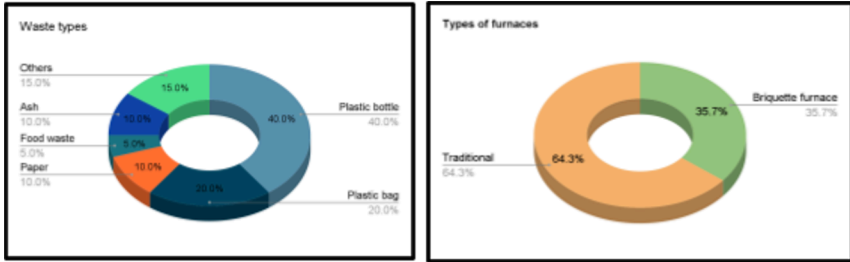


Fig. 6 Types waste and furnaces

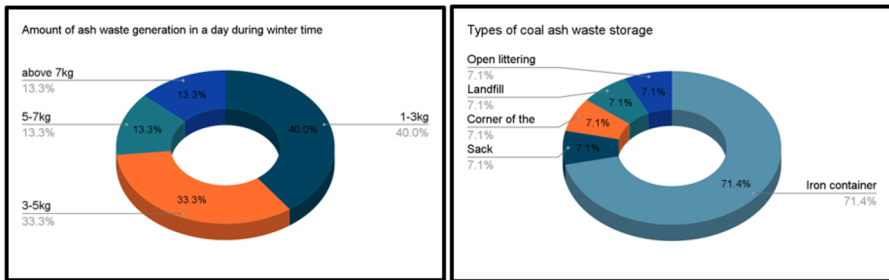


Fig. 7 Amount of ash waste generation in a day and coal ash waste storage

4. Conclusion

This study reveals that rapid urban expansion and widespread reliance on coal-based heating in Mongolia’s ger districts have resulted in significant soil pollution due to household coal ash disposal. The key findings of this study are as follows:

1. Ash samples contained extremely high concentrations of heavy metals (Pb, Zn, Cu, As), with lead (Pb) levels reaching up to 2950 mg/kg almost 50 times higher than Mongolia’s soil quality standards.
2. Soil samples collected near informal ash dumps, former mining sites, and household heating zones exhibited elevated heavy metal contamination, indicating pollutant migration into surrounding soils.
3. Both pXRF and ICP-OES methods produced consistent and reliable results, confirming pXRF as an effective rapid screening tool for field assessments.
4. Continuous disposal of coal ash on open ground contributes to long-term soil degradation, increasing the risk of bioaccumulation of toxic metals and potential groundwater contamination.
5. The presence of heavy metals in ash and contaminated soils poses significant health risks, particularly

to vulnerable populations such as children, due to exposure in residential areas where ash is dumped and vegetables are cultivated.

6. Geoaccumulation Index (Igeo) analysis revealed moderate to extremely high pollution levels for Pb, Co, Cr, and Zn, with pollution hotspots identified near landfill sites and thermal power plants.
7. Household surveys confirmed prolonged resident exposure to contaminated soils, inadequate ash disposal practices, and insufficient municipal waste management services, all of which contribute to environmental pollution. Public awareness of these risks remains low, posing a particularly high risk to children who often play with coal ash, thereby increasing the likelihood of health issues.
8. These findings underscore the urgent need to develop and implement sustainable waste management systems, enhance public awareness programs, and introduce targeted policy interventions to reduce environmental and public health risks in ger districts. As an immediate priority, efforts should focus on increasing public awareness about the toxicity of coal ash. Additionally, households should designate safe, enclosed storage areas within fenced yards to prevent the spread of ash and minimize exposure, especially for children until it is collected by the responsible waste management company (Nalaikh TUK) within 2-4 weeks.

5. Recommendation

1. Develop and implement comprehensive solid waste management systems specifically targeting coal ash collection and safe disposal in ger districts.
2. Increase public awareness campaigns about the environmental and health risks of improper ash disposal and encourage safe handling practices.
3. Encourage households to establish safe, enclosed storage areas within fenced yards to prevent the spread of coal ash and reduce exposure risks.
4. Shorten the collection intervals, particularly during winter, to 1–2 weeks, ensuring timely removal by the responsible waste management company (Nalaikh TUK).
5. Promote the use of cleaner, alternative fuels and more efficient heating technologies to reduce coal ash generation.
6. Initiate targeted soil remediation programs in contamination hotspots to restore soil quality and prevent further ecological damage.
7. Enforce regulations and establish buffer zones around thermal power plants, landfills, and other pollution sources to minimize pollutant migration.
8. Support research and development of resource recovery and recycling methods for household coal ash within a circular economy framework.
9. Employ portable X-ray fluorescence (pXRF) devices as rapid, cost-effective screening tools for ongoing monitoring of soil contamination in urban and peri-urban areas.

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