

Article

Improving the Methods of Solid Domestic Waste Disposal to Reduce Its Human Impact on the Environment

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Abstract: Kazakhstan is embarking on a fresh approach to managing waste, aiming to recycle and repurpose solid household waste while integrating innovative, eco-friendly technologies for its treatment and disposal. The main goal is to reduce the amount of waste sent to landfills and instead convert it into more stable forms, lessening its harmful impact on the environment. This effort requires a comprehensive strategy, especially as existing landfills still need to be managed and rehabilitated when they reach capacity. It is essential to use municipal solid waste as a resource for producing various goods, which not only helps in landfill management but also aligns with principles of sustainability. This approach aligns with circular economic principles and helps to reduce the technological impact of landfills on the surrounding environment. The main types of waste in the Aktas landfill were identified as a result of this research: it is glass, of which only 3% is recycled. In our results, the setup allowed for the extraction of valuable components from the fine fraction, which can then be recycled. This enriches the organic material ready for composting (organo-mineral raw material mixture) with food waste.

Keywords: waste; disposal; glassware; technogenic soil; landfills; secondary materials



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1. Introduction

Improving the methods of solid household waste (SHW) disposal is a crucial aspect of modern environmental strategies. As populations grow and urbanization increases, the volume of waste produced continues to rise, creating significant ecological challenges. Improperly managed SHW can lead to soil, water, and air pollution, negatively impacting human health and ecosystems.

Chuprova L.V. and Mishurina O.A. noted in their article that to reduce the environmental impact of solid household waste, it is essential to implement and advance effective disposal methods. Modern approaches include several key strategies.

The first method is waste separation and sorting, which means that efficient sorting of waste at the collection stage significantly increases the amount of recyclable materials. Separating waste into categories such as organic, plastic, paper, glass, and metal facilitates further recycling and disposal processes [1]. Then, recycling and reprocessing reduce the volume of solid household waste sent to landfills and allow for the reuse of secondary materials in the production of new goods. This reduces the need for primary resources and lessens the burden on natural ecosystems. Composting organic waste is an environmentally friendly method for disposing of organic waste such as food scraps and plant materials. The resulting compost can be used in agriculture as a natural fertilizer. The next method is energy recovery, where waste is burned to produce energy, providing a dual benefit of waste reduction and energy production. However, modern technologies must be used

to minimize harmful emissions from incineration. The last method is waste reduction. Preventing waste generation is one of the most effective ways to address the solid household waste problem. This includes developing eco-friendly packaging, reusing goods and materials, and adopting sustainable consumption practices.

Developing and implementing these methods requires a comprehensive approach, including legislative initiatives, increasing public environmental awareness, and investing in modern technologies. Enhancing SHW disposal methods not only protects the environment but also creates new economic opportunities through job creation and the development of the green economy.

Last year, according to the Environmental Performance Index (EPI), the Republic of Kazakhstan took 93rd place out of 180 [2]. The EPI index is a composite indicator consisting of 40 different indicators in different ecological areas (water, air, biodiversity cleanliness, etc.). Analysts examined two indicators—the solid household waste (SHW) and commercial waste collection and treatment coefficient, as well as the coefficient of recycling. By the metric of SHW and commercial waste collection, Kazakhstan takes 88th place, then in terms of waste recycling it takes 175th place [2]. The country lags behind not only developed countries but also its neighbors in the EAEU (Eurasian Economic Union) and Central Asian states in solid-waste processing. Analysts at Yale University indicate that the waste recycling rate in Kazakhstan last year was 3.8%, while the maximum rate achieved in the world was 67.1%.

In 2022, the share of solid-waste selection and processing in the Republic of Kazakhstan amounted to 25.4%, having increased over the year by only two percentage points. According to the Ministry of Ecology and Natural Resources of the Republic of Kazakhstan (MENR), only 1.1 million tons passed through a sorting belt or waste-processing plant out of 4.3 million tons garbage last year. The same dynamics were observed in industrial recycling.

According to the national project “Green Kazakhstan”, approximately the same dynamics—3–4%—are expected by MENR specialists from environmental program implementation in the solid-waste processing field in the next 2.5 years. If all planned plans are implemented by the end of this year, then by 2024, the level of waste sorting and recycling should be 27% and for industrial waste 42%, and in December 2025—34% and 46%, respectively.

The Karaganda region is among the regions with a large sorting-and-processing share, where 54.6% of waste reaches the sorting belt. The category of regions with processing average share included Atyrau (27.5%), Mangistau (32.1%), and Pavlodar (27.3%) regions, as well as Shymkent (30.3%).

Most regions had indicators below the Republican level last year. In 2022, 14 regions did not reach 25.4%. The minimum shares are in the Ulytau (0.1%) and Abay (1.6%) regions, which can be explained by a recycling process concentration in regional centers and low involvement in the separate collection process in some districts. This immediately became noticeable after the administrative separation of these regions from the East Kazakhstan and Karaganda regions.

Combining two indicators—sorting and recycling—does not show an overall picture of waste management in Kazakhstan. Each of these sections has its own characteristics and problems. For example, not all Kazakh cities and regions have purchased containers for separate waste collection, at least by “wet” and “dry” fractions, not to mention the material types. To be more precise, only 64.3% of the country’s 207 cities and districts have introduced a separate collection system for solid waste, and only half of all settlements have sorting lines.

It depends on the local executive bodies’ activity. According to art. 351 of the Environmental Code of the Republic of Kazakhstan, the akimats must organize measures to stimulate a reduction in the volume of waste disposal [3].

Kazakhstan has over 3000 landfills for solid household waste, but many of them do not meet modern environmental standards. A significant number of these landfills are overloaded and in poor condition, increasing the risk of environmental contamination.

Improper waste disposal leads to the generation of landfill gases and leachate, which can contaminate soil, groundwater, surface water, and the atmosphere. These pollutants pose serious threats to public health and ecosystems. Only a small percentage of waste is recycled in Kazakhstan, mainly due to underdeveloped sorting and recycling infrastructure. As a result, a large portion of solid household waste is sent to landfills without any prior treatment. One of the reasons for the inefficiency in waste management is the lack of effective legislative regulation and oversight. Existing laws and standards are not always effectively enforced, hindering the transition to more modern waste disposal methods. The government of Kazakhstan recognizes the need to improve waste management and is taking steps to adopt more sustainable technologies. Recent years have seen the implementation of programs aimed at modernizing landfills, developing infrastructure for waste sorting and recycling, and promoting separate waste collection among the population.

Overall, while landfilling remains the predominant method of waste disposal in Kazakhstan, the country is gradually moving towards more sustainable and environmentally friendly solutions. Enhancing legislation, investing in infrastructure, and increasing public environmental awareness are key factors in this transition.

Landfilling is the primary method of waste disposal in Kazakhstan, with both regulated and illegal dumpsites being widespread. The issue of collecting and recycling secondary materials is becoming increasingly critical for the country's economy, unlike in Europe, where recycling is well-established.

Landfill disposal is favored in Kazakhstan due to the relatively low cost of land compared to other waste-management methods. Mixing recyclables with other waste, especially organic waste, makes recycling unprofitable without separate collection systems.

However, landfill disposal has significant downsides, such as long-term land use, loss of valuable materials due to lack of sorting, and environmental risks from the migration of pollutants. Many Kazakhstani landfills, some operating for over 20 years, do not meet sanitary standards, and illegal dumpsites are common. These sites are major sources of environmental pollution [4].

The preference for landfilling is due to the low cost of land compared to other waste-management methods. However, the lack of separate collection makes recycling unviable, especially when recyclables are mixed with organic waste.

Landfills have several drawbacks: they occupy land for long periods, valuable materials are lost without proper sorting, and they pose environmental risks from pollutant migration. Many landfills in Kazakhstan, operating for over two decades, do not meet sanitary standards, and illegal dumpsites are widespread. These sites contribute significantly to environmental pollution.

To mitigate the adverse effects of landfills on the environment and public health, it is crucial to select landfill locations based on geological, hydrological, and social criteria; implement technical measures to prevent pollutant spread; and conduct environmental monitoring around landfills to ensure protective measures are effective and address any issues promptly.

The aim of the study is to stabilize organic waste and separate the fine fraction from solid waste using a disc sieve and similar mechanisms, further composting in the piles. The resulting man-made soil is used as a material for dumping waste and dumping slopes of landfills. Also in this study is proposed an improvement to the artificial soil production process by including mechanized treatment of the fine SHW fraction. This involves adding an air separator to remove light fractions and an optical separator to extract glass shards.

2. Materials and Methods

Lab methods used for our experiments in this study: The various techniques collected and applied to analyze the data, such as information synthesis, systems analysis, expert evaluations, and mathematical statistics. The research was conducted in laboratories including the research and testing center "Sapa" and the "Construction materials, construction, and architecture" research institute.

The subject of the study is the “Aktas” landfill. This municipal solid-waste landfill is located 15 km south of Shymkent, along the Shymkent–Tashkent highway, 3.367 km south and 2.832 km west of “Akzhar” village. The site is 1.3 km west of the main road and borders undeveloped land. There are no residential areas, water bodies, protected areas, or green spaces near the site. The total area of the landfill is 29.0 hectares.

The existing landfill is intended to serve the residents of the “Abay” district and Shymkent city, which have a total population of 219,622 people, as well as 12 new settlements with a population of 25,912 people.

The region has a sharply continental climate. The maximum air temperature is +44 °C, and the minimum is −34 °C. The average annual precipitation is 570 mm, with predominant wind directions being east and southeast. There are no water bodies near the landfill.

The operational zone includes a service building, a garage for machinery, and concrete-paved, lit, and fenced areas. The landfill accepts all consumer waste generated in residential areas, organizations, institutions, and commercial enterprises, including street trash, waste from heating systems in homes, and debris from minor home repairs. All operations for the deposition, compaction, and covering of solid waste at the landfill are mechanized.

The total expected waste intake for 2025 is estimated at 92,823.45 tons per year. Compared to previously established emission standards, the volume of pollutants and waste has increased due to population growth and the addition of institutions for waste collection. The site is classified as a Class I hazard with a sanitary protection zone of 1000 m. Figure 1 illustrates a situational map of the facility and shows a site map with marked sources of pollutant emissions.

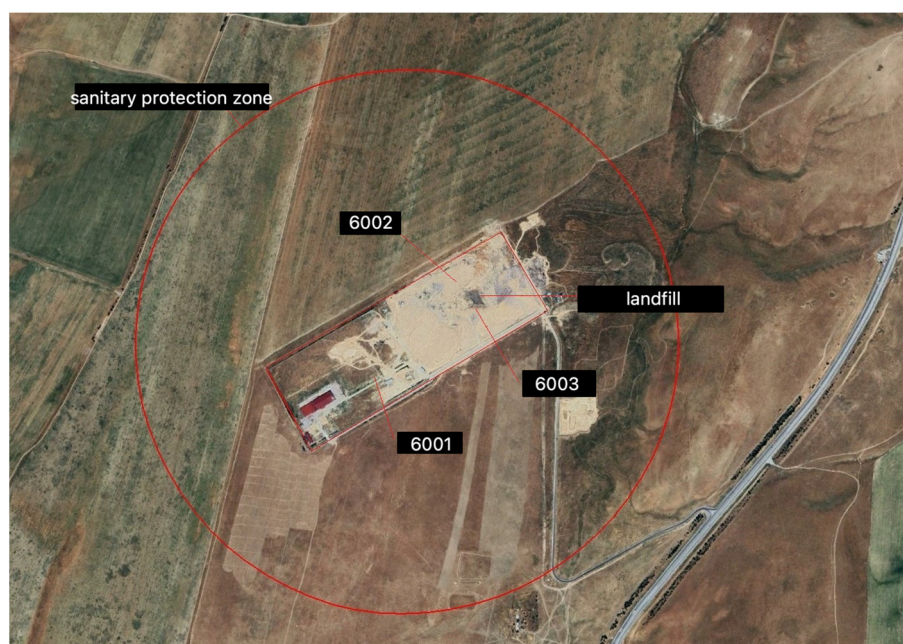


Figure 1. Map of the facility (6001—activities related to loading and unloading (such as refilling and compaction); 6002—management of solid-waste landfill (storage of garbage); 6003—transportation by motor vehicles).

The solid household waste landfill operates 24 h a day, 365 days a year. The accumulation of waste at these landfills leads to increased levels of methane and other decomposition gases due to ongoing chemical processes. This biogas is produced by bacteria that break down organic materials.

The landfill has a projected lifespan of 10 years, with a planned height of 2.9 m and a total capacity of 1,660,901.08 tons. Each year, it is expected to receive $W_r = 92,823.45$ tons of waste.

The landfill uses a specific method for handling waste. Garbage trucks unload at designated areas divided into two sections: one for unloading and one for bulldozer operations. This unloading process takes 1–2 h. The waste is deposited in a specific area allocated for that day, with strict rules against random dumping. The working area is 5 m wide and up to 60 m long. Bulldozers spread the waste into layers up to 0.5 m thick. These layers are compacted to form a mound with a gentle slope, reaching a height of 2 m. Subsequent mounds are built adjacent to the previous ones, layering the waste from bottom to top. Portable mesh fences, 4 m high, help contain small waste particles during unloading.

The landfill includes a marker to monitor waste compaction. During the summer, when fire risks are higher, the waste is moistened, using 10 L of water per cubic meter of solid household waste. Compaction levels are checked twice a year. Intermediate and final covers of the compacted waste layers are done with soil, and the area is greened after the final cover. The landfill's outer slope is maintained at a 1:4 ratio and inspected quarterly. Burning solid household waste and scavenging are strictly prohibited. Radiation checks ensure no radioactive waste is dumped.

During the landfill's operation, the organic waste undergoes biothermal anaerobic decomposition due to microbial activity.

At the “Aktas” landfill near Shymkent, a composting process is used for organic waste. The current procedure for producing technogenic soil involves several stages. The first is the initial sorting of mixed waste to extract fine fractions (0–80 mm). The next is the separation of ferrous metals using a magnetic separator. Afterward, the remaining organic mineral blend is transferred to a composting facility, where it undergoes windrow composting for a period of 88 days. The resultant technogenic soil is then utilized by being buried as biostabilized material.

In Figure 2 you can see a breakdown of the composition of both the mixed solid household waste (SHW) accepted at the “Aktas” landfill and the separated fine fraction (0–80 mm).

Looking at the data in Figure 2 shows that 50.7% of solid household waste (SHW) can either be composted or, if composting is not available, sent directly to landfills. In the small-sized debris from this waste, there are significant amounts of items that cannot be composted, like glass pieces (up to 20%), plastics, and stones. Glass, which has value, could be sold if sorted properly. However, without extra sorting, valuable materials might end up in landfills. This would make the technogenic soil less suitable for covering slopes because it would contain items like glass and plastic that cannot decompose and could be blown away by the wind. Laboratory tests by Austrian company “Binder+Co AG” confirmed the feasibility of glass-shard extraction. Figure 3 shows the appearance of the separated fine fraction.

Within solid household waste (SHW), there is a portion that is mineral-based, containing metals, ceramics, and glass. Glass, particularly in the form of fragments, makes up roughly 7% of the SHW, with a significant portion originating from glass containers. These glass fragments are currently subject to state standards, which categorize them based on color (Table 1) and sort them into grades 1 and 2, depending on the presence of green and brown glass impurities.

In Table 1, the total SHW mass is 100%, 0–80 mass is 50.7%, and 0–80 mass² is 100%.

According to standards, glass cullet is classified by color and sorted into two grades based on the amount of green and brown glass impurities present [5].

The color classification of glass cullet includes the following types:

BS—Colorless
 PST—Semi-white container glass
 PSL—Semi-white sheet glass
 ZS—Green
 KS—Brown

The grade of the glass cullet, either grade 1 or grade 2, is determined by the content of green and brown glass impurities.

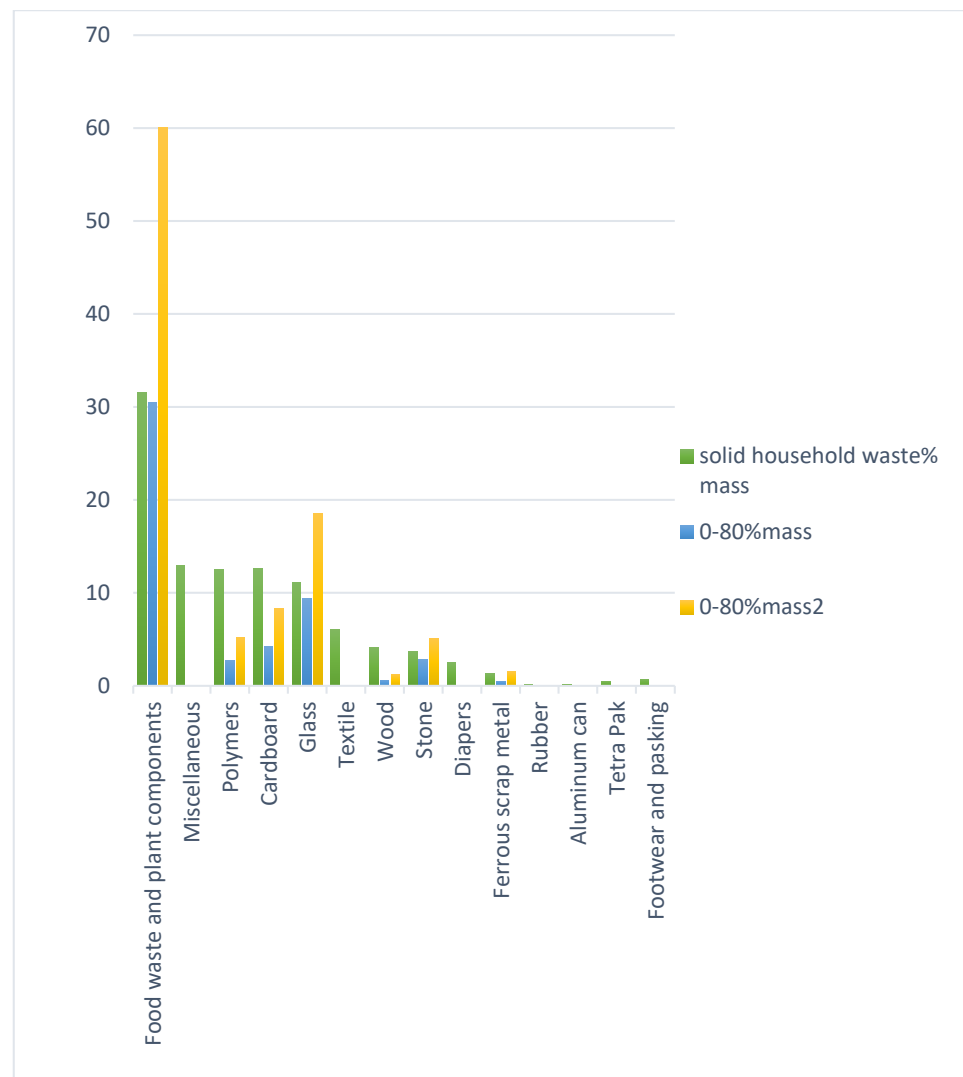


Figure 2. Morphological composition of SHW and separated fraction 0–80 mm.



Figure 3. Fine fraction of SHW (0–80 mm).

To evaluate the potential utility of these glass fragments in construction materials, an analysis and a devised plan for their collection and application were conducted. As shown in Figure 1, there are three sources of pollution (activities related to loading and unloading (such as refilling and compaction), management of the solid-waste landfill (storage of garbage), and transportation by motor vehicles). Our investigation revealed that the

primary sources of glass fragments include SHW, residues from the food and pharmaceutical industries, as well as discarded special and window glass [6]. The main beneficiaries of these glass fragments are the glass industry itself, along with sectors involved in construction and insulation materials, road building, and various other industries. Only 3% of glass shards are recycled into new products [7]. The proportion of glass entering the recycling process reaches 20%, with a total of 3277.2 thousand tons collected in 2009 and 655.4 thousand tons processed [8].

Table 1. The morphological composition of the fine fraction and the result of its preparation.

No	Name	Fine Fraction	Organo-Mineral Raw Material Mixture	Glass Cullet	Alternative Fuel	Scrap Metal
		% Mass	% Mass	% Mass	% Mass	% Mass
1	Cardboard	8.3	7.7	-	0.6	-
2	Polymers	5.3	0.1	-	5.2	-
3	Wood	1.2	1.0	-	0.2	-
4	Black metal scrap	1.0	0.2	-	-	0.8
5	Glass	18.5	1.4	17.1	-	-
6	Food waste and plant components	60.1	56.6	-	3.5	-
7	Stone	5.5	5.5	-	-	-
8	Other	0.05	0.05	-	-	-
	IN TOTAL	100	72.6	17.1	9.5	0.8

As E.V. Baranov et al. highlight, glass-shard recycling is particularly beneficial among all SHW components. However, the main challenge in reusing glass containers lies in separating them from other solid household and industrial waste. Internationally, there is extensive experience in collecting and recycling glass shards [9]. In large cities, specialized companies primarily handle glass waste collection. For example, in the USA, glass manufacturing companies manage the collection and initial processing of glass shards, often installing sorting and recycling facilities directly at glass factories.

There are three main routes for reusing discarded glass containers:

1. Reusing them as secondary raw materials for new glass containers.
2. Using them as primary raw materials in producing various construction materials.
3. Disposing of them as part of SHW in landfills.

Globally, the primary use of glass shards is in producing new containers (jars and bottles), as this mass production process has less stringent requirements for the consistent chemical composition of the glass and allows for using mixed-color and composition glass shards.

However, the production of glass containers is not the only direction for glass-shard recycling. Another significant use is in producing foam materials for insulating walls, ceilings, roofs, manufacturing sandwich panels, insulating pipelines, thermal and refrigeration units, and as a lightweight concrete aggregate. Structurally, these materials can be produced in three distinct forms: blocks (or panels), granules (construction sand or gravel), and shapeless pieces (construction rubble).

Foam glass is an entirely inorganic insulating material that undergoes thermal treatment at temperatures between 700 and 800 °C. This material is non-combustible and does not support burning, making it an excellent choice for fire safety. Its fire resistance, based on insulating capability, lasts 30, 45, and 60 min for thicknesses of 40, 80, and 100 mm, respectively. Consequently, using foam glass can significantly reduce the fire hazard in buildings and structures, preventing the spread of flames in case of a fire. Additionally, like

regular glass, foam glass is environmentally friendly, eliminating the need for widely used phenolic-based materials or hazardous polystyrene foam [10].

Foam glass is not attractive to rodents and does not provide shelter for insects, making it highly effective for use in constructing warehouses, food-storage facilities, cottages, and cold storage insulation.

Another valuable use for recycled glass is in the production of fiberglass. Additionally, one of the raw materials for manufacturing insulating products is mineral wool, which contains 25% recycled glass. Some international companies are exploring the possibility of using crushed glass in agriculture to improve soil structure. There is also experience in using glass waste as a filler in producing paints, wallpaper, plastics, and abrasive materials for glass sandpaper and grinding wheels.

Therefore, the utilization of recycled glass in manufacturing various materials and products holds enormous potential, mainly due to the renewable nature of the raw material [11].

In Shymkent, a process has been established for collecting glass containers for recycling, reducing environmental impact. Specialized collection points allow citizens to return used glass bottles and containers. Through testing at “Eurokristall’s” facilities, they found that the more glass passes through the optical separator, the cleaner it gets. This led “Eurokristall” LLP to invest in an air separator to assess the initial phase of their new technology. “Eurokristall” LLP specializes in producing various glass containers for food and pharmaceuticals, ranging from 150 mL to 2 L, available in both clear and colored glass.

Their experiments focused on separating fine materials from mixed municipal waste, recovering ferrous metals, and isolating light fractions suitable for alternative fuels. The heavier materials were sent to a glass recycling plant, where they focused on extracting recyclables from fractions sized 0–80 mm. “Eurokristall” LLP uses a series of optical separators from “Binder+Co AG” (Gleisdorf, Austria) to produce a clean, color-sorted glass cullet. The experiments showed that achieving the desired purity of glass cullet requires a fine fraction of municipal solid waste to pass through the optical separator twice.

Through our experimental trials, a technological process was crafted to manage the household solid-waste (HSW) fine fraction and extract extra secondary resources. This process unfolds through a series of steps:

Step 1. The 0–80 mm fraction is sifted using a disc screen.

Step 2. Ferrous metals are extracted using a magnetic separator.

Step 3. Light fractions are isolated with an air separator.

Step 4. Glass cullet is extracted using an optical separator.

A final check for any lingering magnetic materials is carried out with an additional magnetic separator.

3. Results

This setup allowed for the extraction of valuable components from the fine fraction, which can then be recycled. This enriches the organic material ready for composting (organo-mineral raw material mixture) with food waste. Table 1 shows the results of these experiments, detailing the useful components extracted from the fine fraction of HSW. This process produces a blend of organo-mineral raw materials, glass cullet, alternative fuel, and scrap metal. After extraction, the organo-mineral mixture contains mostly biodegradable waste, about 90% (such as food waste and plant components, cardboard, textiles, e.g.). When composted outdoors, this blend transforms into a consistent technogenic soil ideal for slope stabilization.

Glass cullet consists of fragments from different glass items like containers, bricks, and windowpanes. It serves as a valuable secondary raw material, offering multiple reuse cycles in production and notably cutting down on energy and material expenses. With the proposed processing scheme, up to 100 kg of glass cullet can be obtained from each ton of waste.

Alternative fuel encompasses high-calorie fractions that cannot be recycled, including paper, polymers, textiles, wood, and tetrapak. In Europe, over 30 years of present practice involve using alternative fuel from SHW and adopting it in waste management. Industries such as cement, metallurgy, and energy are this fuel type's major consumers. The calorific waste-derived fuel's value rivals that of coal, ranging from 3500–6000 kcal/kg, depending on the grade. By using the waste's energy potential as fuel, the waste volume in landfills is reduced, and the consumption of primary energy resources (hydrocarbons) is reduced.

The technogenic soil's production process is shown in Figure 4. Item (a) indicates before modernization and (b) after modernization. The initial fine fraction (27.4%) is recovered as valuable secondary materials, and 51% is converted into technogenic soil with the upgraded technology. While the older process yields more technogenic soil, it also includes all the components that the modernized process extracts for reuse, meaning those materials would otherwise need to be disposed of.

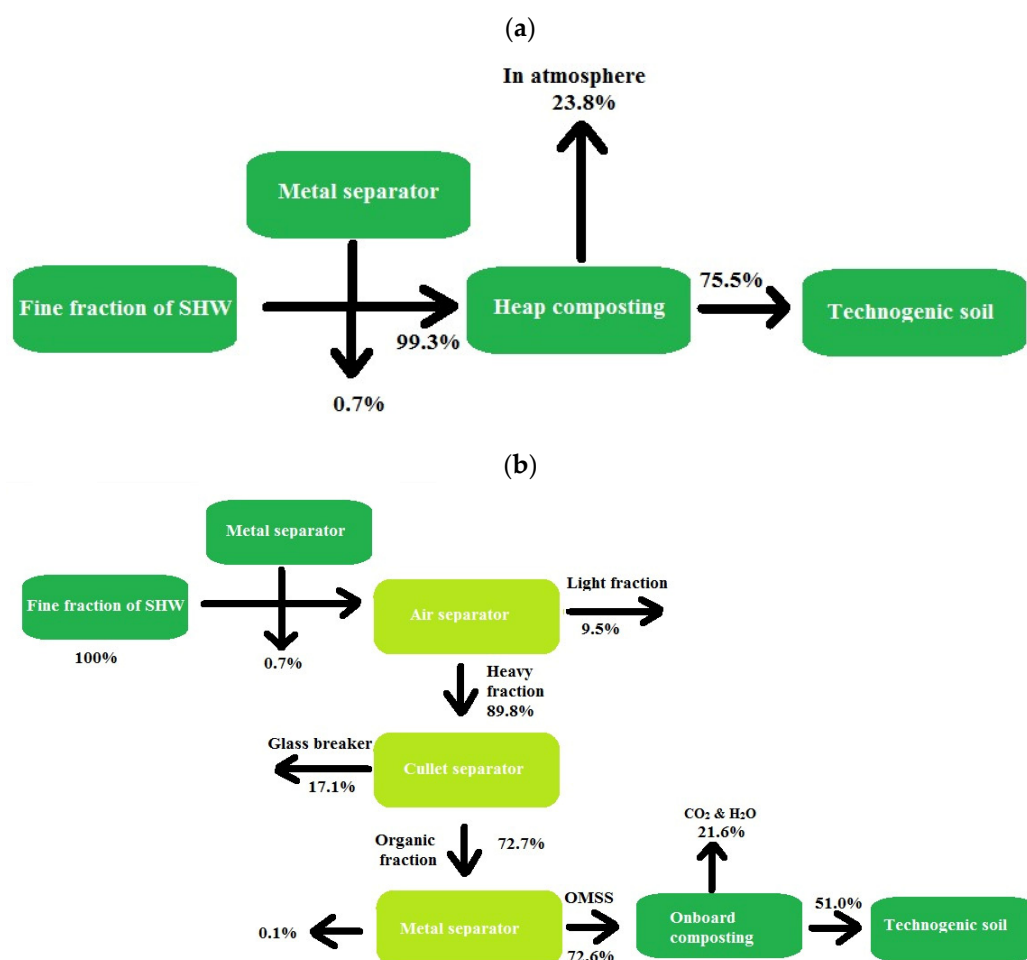


Figure 4. Flowchart for processing SHW fine fraction: (a) before modernization; (b) after modernization (OMSS—organo-mineral raw material mixture).

The proposed mechanical-biological approach to managing the finer fraction of solid household waste can unlock its full potential. This method includes separating out glass fragments, lighter materials that can be used as alternative fuel, and creating artificial soil. Conserving our natural resources and reducing the environmental impact caused by landfills is the main objective here [12].

The “Aktas” landfill’s composting area is like an open space with a sturdy, compacted base covered by a waterproof sheet. Along the edges, there are slopes and drains to collect any liquid that forms during composting, as well as channels for rainwater runoff.

Inside this area, a loader equipped with a mix of organic and mineral materials creates long parallel ridges in a trapezoid shape (Figure 5). To keep these ridges well-aerated, a special machine called an aerator is used. It works by mixing the composting materials with a rotating shaft as it moves along the ridge, all while maintaining the ridge's shape (Figure 6).



Figure 5. Composting ridges.



Figure 6. The aeration process of composting ridges facilitated by a turning machine.

In the composting area, the small bits of household waste break down naturally inside these ridges [13]. Initially, this material has all the tiny organisms needed for breaking down. To get them active, the decomposing mass is stirred and ensured to stay damp. Organic bits break apart, giving off heat through biochemical reactions during microorganism processing. In this process, they need oxygen. The ridges are watered twice a week when it is warmer than 10 °C and once a week when it is colder. Liquid is collected to keep the composting material just right in moisture. The material gets smaller as organic stuff breaks down, letting out carbon dioxide and moisture during composting. About 30–40% of the organic stuff turns into carbon dioxide and water. The breaking down is slowed,

and a stabilizing phase is started after about 60 days which lasts about 30 days. The pH and temperature change during this time. The composting result is technogenic soil, as is shown in Figure 7.



Figure 7. Technogenic soil.

After the initial treatment of the fine fraction of solid household waste (SHW) and its subsequent composting, enriched technogenic soil is obtained containing abundant biodegradable elements. To verify the robust biological potential of the technogenic soil derived from SHW, its agrochemical characteristics are assessed. Furthermore, an analysis of heavy metal levels is conducted on the technogenic soil. The findings from these assessments are detailed in Tables 2 and 3.

Table 2. Agrochemical indicators of technogenic soil.

No	Indicators	Unit	Value
1	pH	pH unit	7.80 ± 0.28
2	Organic Carbon	%	30.2 ± 1.8
3	Total Nitrogen	%	1.82 ± 0.18
4	Ammonium Nitrogen	mg/kg	606 ± 54
5	Nitrate Nitrogen	mg/kg	2430 ± 195
6	Phosphorus	mg/kg	1640 ± 152
7	Potassium	mg/kg	1335 ± 104

Table 3. The content of gross forms of heavy metals (mg/kg) in technogenic soil.

No	Heavy Metals	Concentration	Maximum Permissible Concentrations/Approximately Permissible Concentrations
1	Cu	86 ± 18	132
2	Zn	385 ± 51	220
3	Pb	143 ± 36	130
4	Cd	0.37 ± 0.09	2
5	Ni	22 ± 7	80
6	Mn	95 ± 13	1500
7	Hg	0.46 ± 0.12	2.1
	As	0.7 ± 0.3	10

Table 2 shows that technogenic soil contains high levels of essential nutrients such as nitrogen, phosphorus, and potassium, which are necessary for plant growth and development. This means that the resulting product will promote the growth of seedlings. The

optimal carbon to nitrogen (C/N) ratio is 16.6; at values above 20, nitrogen availability decreases, and microbial metabolism slows down, leading to nitrogen deficiency in plants. The ammonification activity is the primary decomposition process for nitrogen-rich organic compounds and is proved by ammonium nitrogen presence. This process involves various microorganisms, including those that thrive in oxygen-rich environments and those activated in oxygen-deprived conditions, as well as fungi and actinomycetes. Nitrate nitrogen formation occurs during nitrification, the nitrogen transformation's subsequent stage in the soil. The nitrification intensity serves as soil fertility's indicator, as the bacteria responsible require specific conditions to thrive. Any deviations from these conditions, such as unfavorable temperatures, inadequate oxygen, or high humidity, can hinder their activity and affect nitrate nitrogen levels in the soil. Changes in nitrate nitrogen concentration signal ongoing transformations of nitrogen-containing organic substances, with nitrification intensity often indicating the readiness or maturity of compost concerning organic materials [14].

The nitrate forms' predominance in the technogenic soil indicates its advanced maturity as compost material and adherence to the necessary oxygen conditions, which facilitate the breakdown of nitrogen-containing organic components.

It is evident that the levels of zinc and lead exceed the maximum permissible concentration for soils in residential areas by 1.8 times and 1.1 times, respectively, as shown in Table 3. However, copper, cadmium, nickel, manganese, mercury, and arsenic levels fall within acceptable limits. Nonetheless, it is crucial to consider that the variability in recorded data on heavy metal content depends on the initial materials. Therefore, the feasibility of utilizing the resulting product beyond waste disposal sites was not explored in this study.

4. Discussion

The waste directed to the sorting complex undergoes processing of the fine fraction (0–80 mm), enabling the cullet extraction, material suitable for alternative fuel, and scrap metal. The residues from the sorting process (organo-mineral mixture) are directed for composting, leading to technogenic soil creation suitable for isolating slopes during landfill operation. Any surplus technogenic soil is utilized as stabilized waste, thereby reducing greenhouse gas emissions and filtrate toxicity.

The filtrate generated at the waste disposal site is collected via a drainage system and directed to the lithification area. Here, lithification production occurs—a solid, environmentally safe product resulting from the filtrate interaction with aluminum sulfate and shale ash. It serves as a cover material for waste during landfill operation and contributes to surface leveling and gas drainage systems during landfill reclamation. Technogenic soil and lithification effectively fulfill the soil resource needs the landfill.

Implementing this plan helps manage the solid-waste resources to reduce landfills' impact on the environment by conserving soil, cutting down on greenhouse gases, reducing leachate toxicity, and using landfill runoff alongside industrial waste.

This resource management plan was tested at the “Aktas” landfill in Shymkent.

Furthermore, new techniques for creating and applying technogenic soil at the “Aktas” landfill were introduced. Experimental trials involving the fine waste treatment resulted in the production of 1400 tons of technogenic soil, along with 470 tons of cullet, 260 tons of alternative fuel material, and 22 tons of scrap metal. The technogenic soil was then utilized to cap the landfill slope's section in March 2024, with vegetation growth's subsequent monitoring. Notably, vegetation, initially including pumpkin, tomato, watermelon, and zucchini seeds from the technogenic soil, began to populate the slope within the first year. Over time, indigenous plant species, particularly various weeds and ruderal plants like nettles, thistles, dock, dandelions, yarrow, tansy, and wormwood, further enriched the vegetation cover.

5. Conclusions

Glass cullet becomes an essential part of producing construction materials and technogenic soil. Properly managing glass waste helps keep our planet clean, and reusing glass containers is the best way to recycle. However, because glass is fragile, glass waste needs careful disposal. Thus, the following conclusions can be drawn from the study:

1. Improving the methods of handling small fractions of household waste is aimed at maximizing the efficient use of waste resources and creating technogenic soil.
2. Processing the fine fraction of household waste (0–80 mm) lets us extract 27.4% of secondary materials: 17.1% glass cullet, 9.5% material for alternative fuel, and 0.8% scrap metal.
3. Processing household waste's fine fraction enriches the organo-mineral mixture with biodegradable components up to 90% during composting.
4. Modernizing the technology to make technogenic soil from household waste's fine fraction means that 27% more secondary resources can also be extracted: glass cullet, material for alternative fuel, and scrap metal. Testing this updated soil production method at the "Aktas" landfill yielded glass cullet—470 tons, alternative fuel material—260 tons, scrap metal—22 tons, and technogenic soil—1400 tons.
5. Using the technogenic soil to cover the landfill slope instead of natural soil saves soil resources.

According to the economic calculation, the unit cost of recycling 1 m³ of filtrate is USD 35, taking into account the depreciation of equipment. To justify the expediency of using this technology, a comparison was made with such a purification method as reverse osmosis. Reverse osmosis has been the most common filtrate-purification technology abroad for more than 10 years and is used both independently and in combination with biological purification methods as the final stage.

This study may be useful for research in the field of solid-waste disposal.

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