Ecological Principles of the Storage and Neutralization of Municipal Solid Waste in Landfills

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Abstract. Solid household waste (SHW) has a significant impact on urban ecology. This study analyzes the ecological foundations of SHW storage and disposal at landfills and demonstrates a scientific approach to sustainable waste management using Geographic Information Systems (GIS), the Analytic Hierarchy Process (AHP), and Multi-Criteria Decision-Making (MCDM) tools. The research findings provide practical guidance for policymakers, urban planners, and local authorities in developing environmentally sound waste management strategies.

INTRODUCTION

- Urbanization and industrial development of cities are intensifying the challenges associated with municipal solid waste (MSW) management.
- Improper waste management practices lead to contamination of soil, water, and air, thereby exerting negative impacts on public health.
- The processes of storage and disposal in landfills must be aligned with scientifically grounded decision-making approaches to ensure environmental safety and sustainability.

LITERATURE REVIEW

Solid waste landfill sites in the Burdur Lake Basin were evaluated using the Analytic Hierarchy Process (AHP) and Geographic Information Systems (GIS); the results confirmed the suitability of existing landfills and identified two new potential sites for future use, demonstrating practical relevance for sustainable waste management [1]. In the Kenitra Province of Morocco, landfill site suitability was assessed using ArcGIS, remote sensing, and AHP, leading to the proposal of two strategic sites that support sustainable waste management aligned with the Sustainable Development Goals (SDGs), while contributing to the protection of public health and ecosystems [2]. In the Marmara region, a machine learning–based system was developed for landfill site selection, where XGBoost achieved the highest performance with an accuracy of 0.8671; SHAP analysis indicated that land use and proximity to airports and industrial areas were the most influential factors, providing a reliable tool for environmentally and economically optimal waste management [3]. Overall, the study highlights the importance of data-driven multi-criteria decision-making tools in solid waste management; the integration of GIS and AHP proved effective in optimizing landfill site selection, enhancing environmental sustainability, and reducing health risks, thereby offering practical guidance for decision-makers in developing sustainable waste management strategies in the context of Gimba town [4].

AIMS AND OBJECTIVES

- To identify landfill sites in accordance with environmental and social criteria.

- To develop a scientifically grounded methodology for sustainable waste management.
- To ensure a strategic decision-making process aligned with the Sustainable Development Goals (SDGs)

RESERCH METHODS

- Data: GIS shapefiles, land-use maps, topographic and hydrogeological data, population and infrastructure parameters [5-10].
- AHP: determination of weights for parameters and criteria.
- MCDM: classification of areas into suitability classes (high, medium, low, unsuitable).
- Remote sensing: land analysis and updating of land-use maps.
- Machine learning (if applied): improving the accuracy of site (polygon) selection and identifying the most influential factors.

Municipal solid waste (MSW) refers to organic and inorganic waste generated as a result of the daily life and activities of individuals, as well as the activities of legal entities, including waste formed within their territories and at landscaping facilities as a result of natural processes (food and plant waste, textile products, packaging materials, glass, rubber, paper, plastic, wood waste, household items that have lost their functional properties, street sweepings, as well as waste generated from the operation of household stoves and heating boilers using solid fuel).

A municipal solid waste landfill is a complex facility intended for the placement, neutralization, and isolation (burial) of municipal solid waste, ensuring protection of atmospheric air, soil, surface water, and groundwater from pollution, and preventing the proliferation of rodents, insects, and disease-carrying microorganisms (dump site).

Municipal solid waste landfills (hereinafter referred to as *landfills*) may be established for settlements of any size. In order to ensure efficient land use and reduce waste transportation costs, it is advisable to establish centralized landfills for closely located settlements.

A properly organized system for the removal and neutralization of municipal solid waste from cities and other settlements plays a decisive role in maintaining sanitary and epidemiological well-being of the population and in reducing the incidence of intestinal infectious diseases. Therefore, sanitary supervision of MSW management systems in settlements is one of the main tasks of the territorial centers of the State Sanitary and Epidemiological Surveillance Service.

Municipal solid waste includes useless, unnecessary, or discarded materials generated as a result of human activities in individual households, public, medical, and other institutions, which must be transported from urban and rural settlement areas to municipal solid waste landfills through a unified centralized system operated by specialized municipal enterprises under local authorities.

These sanitary regulations are intended for use by employees of territorial centers of the State Sanitary and Epidemiological Surveillance Service, ministries, agencies, and design organizations involved in addressing the issues of municipal solid waste management in settlements across the republic.

COMPOSITION AND PROPERTIES OF MUNICIPAL SOLID WASTE

Municipal solid waste (MSW) comprises various items, objects, materials, and residues that are no longer suitable for further use. These wastes are typically classified into the following main groups: paper, food waste, wood, metals, textile products, leather, rubber, glass, stones, coal and ash, indoor and yard sweepings, fallen leaves, other unclassified components, and fines/screenings (particles smaller than 15 mm) [11-34].

The above classification of MSW is determined, on the one hand, by the need to identify valuable components of MSW for subsequent utilization as secondary raw materials for industry or as animal feed; on the other hand, by the need to select rational and environmentally sound methods for their treatment and disposal.

The average morphological composition of MSW is primarily characterized by a significant proportion of food waste (up to 38.4%) and paper (18.9%). In recent years, the share of various products made of polyethylene and plastics in MSW has increased sharply. The composition of MSW components is not constant and varies seasonally; in particular, during summer and autumn the percentage of food waste increases, which is associated with higher consumption of vegetables and fruits by the population during these periods (Table 1).

Municipal solid waste (MSW) is sufficiently specific in terms of its physicochemical characteristics (moisture content, calorific value, and organic matter content); therefore, it can be effectively neutralized by bio fermentation methods at industrial facilities and at specially designed landfills.

TABLE 1 Average morphological composition of municipal solid waste (MSW) in urban areas (percentage by weight)

Fractions of Municipal Solid Waste	Main seasons of the year				Annual average
	winter	spring	summer	autumn	
Paper	29,5	18,3	18,8	18,1	18,9
Food waste	35,3	36,8	39,2	42,2	38,4
Wood	4,7	4,2	3,0	7,8	4,9
Metals	5,0	3,9	2,2	2,3	3,4
Textiles	3,7	3,3	3,9	4,3	3,9
Leather and rubber	2,0	0,7	0,4	0,4	0,8
Glass	4,7	4,5	0,3	1,9	3,7
Stones	6,4	10,5	16,8	8,0	8,9
Other components	17,7	17,8	15,4	15,0	17,1

The content of organic matter in MSW is relatively high (up to 58.3%), and in autumn it reaches up to 66.0%. Combined with a high calorific value (on average more than 1580 kcal/kg per year), this allows MSW to be processed in waste incineration facilities throughout all seasons of the year (Table 2).

TABLE 2 Average chemical composition of municipal solid waste

Main indicators	Winter	Spring	Summer	Autumn	Annual average
Organic matter relative to absolutely dry mass, %	54.3	39.1	61.0	66.0	58.3
Moisture content, %	46.0	43.6	38.9	48.6	44.2
pH value of saline extract	7.1	7.2	7.6	7.4	7.2
Bulk density, kg/m³	355.6	387.6	434.0	406.0	395.0
Calorific value, kcal/kg	1972.4	1508.4	2507.0	1647.2	1581.2

The bacteriological quality of MSW is characterized by low titers of Escherichia coli (10^{-7}–10^{-8}), Clostridium perfringens (10^{-7}), and Proteus spp. (10^{-3}–10^{-5}). Therefore, municipal solid waste poses a potential epidemiological hazard to the population [11].

The bulk density of MSW in urban areas may vary over a wide range (from 355 to 406 kg/m³). For average annual calculations, a value of approximately 400 kg/m³ may be adopted. Given the significant variability of bulk density, it is advisable to determine this parameter specifically for individual settlements within regions of the republic.

CUMULATION RATES OF MUNICIPAL SOLID WASTE

It should be considered that MSW accumulates unevenly throughout the year within settlement areas. The maximum accumulation is typically observed in autumn (1.6 kg/day), while the minimum occurs in winter (0.8 kg/day). This seasonal unevenness in MSW accumulation should be considered when developing optimal schedules for waste transportation and rational utilization. In settlements, the MSW accumulation rate per capita should be assumed, on average, at 1.2 kg/person day (0.0032 m³) or 453 kg/person year (1.1 m³/year).

TABLE 3. Average accumulation rates of municipal solid waste

MSW accumulation indicators per capita	Winter	Spring	Summer	Autumn	Annual average
Average, kg/day	0.8	1.0	1.3	1.6	1.2
Average, m³/day	0.0025	0.0028	0.0030	0.0039	0.0032
Average, kg/year	292	401	474	584	453
Average, m³/year	0.82	1.03	1.09	1.43	1.10
Bulk density, kg/m³	355.6	387.6	434.0	406.0	395.8

Due to the absence of officially approved differentiated standards for MSW accumulation in some public catering facilities, commercial and cultural–public institutions, hospitals, and polyclinics in the Republic of Uzbekistan, calculations may temporarily rely on the standards specified in the sanitary regulations of the Russian Federation titled “Sanitary rules for the collection, storage, transportation, neutralization, and utilization of municipal solid waste (MSW) in cities of the Republic of Uzbekistan” (SanPiN of the Republic of Uzbekistan No. 0068-96).

For specific regions, cities, and districts, these accumulation standards may be refined by the territorial centers of the State Sanitary and Epidemiological Surveillance Service based on specialized studies of sanitary and hygienic nature.

DETERMINATION OF SITES FOR MUNICIPAL SOLID WASTE LANDFILLS

Municipal solid waste (MSW) landfills are specialized facilities intended for the isolation and neutralization of MSW and must ensure and guarantee the sanitary and epidemiological safety of the population. Such landfills may be established for settlements of any size; however, the establishment of centralized landfills serving groups of settlements is preferable.

The organization operating the landfill shall, taking into account occupational health and industrial sanitation requirements for on-site personnel, develop the landfill operating regulations and режим, prepare instructions for MSW acceptance, ensure control over the composition of incoming waste, maintain continuous (24-hour) accounting of waste deliveries, control waste distribution, and ensure the full technological cycle of waste isolation.

The site selected for the construction of an MSW landfill must have a conclusion from the territorial centers of the State Sanitary and Epidemiological Surveillance Service (DSENM) confirming its compliance with sanitary and epidemiological regulations.

MSW landfills accept waste from residential buildings, public buildings and institutions, commercial and public catering facilities, street, garden, and park sweepings, construction waste, as well as certain types of industrial waste classified as hazard classes 3–4. The list of such industrial wastes shall be coordinated with the territorial centers of DSENM.

The neutralization of solid, liquid, and paste-like radioactive waste shall be carried out at specialized landfills organized in accordance with the basic sanitary regulations for ensuring radiation safety in force within the territory of the republic.

The disposal and neutralization of solid and paste-like wastes generated by industrial enterprises that contain toxic substances and heavy metals (hazard classes 1–2), as well as flammable and explosive wastes, shall be performed at specialized landfills established in accordance with the sanitary regulations of the Republic of Uzbekistan (SanPiN Nos. 0127-02 and 0128-02, including the sanitary rules for inventory, classification, and neutralization of industrial waste and the hygienic classification of toxic industrial wastes under the conditions of the Republic of Uzbekistan).

Direct recovery of secondary raw materials from waste transportation vehicles is not permitted. Waste sorting and selective collection are allowed only under strict compliance with sanitary and hygienic requirements.

The territorial centers of DSENM, in accordance with annual work plans, carry out sanitary supervision of soil conditions, ensuring compliance with these Rules, as well as with hygienic standards for chemical substances in soil approved by the Ministry of Health of the Republic of Uzbekistan (including maximum permissible concentrations), and with indicators for assessing the sanitary condition of soils, in accordance with the relevant sanitary regulations and methodological guidelines approved by the Ministry of Health.

DISCUSSION

- Proper landfill site selection enhances environmental sustainability and protects water and soil resources from contamination.
- It contributes to improved urban public health and increased economic efficiency.
- The integration of machine learning (ML) and geographic information systems (GIS) optimizes decision-making processes.

CONCLUSIONS

The storage and neutralization of municipal solid waste at landfills require an environmentally sound and scientifically justified approach. The application of GIS, AHP, and MCDM tools ensures the optimal selection of landfill sites for sustainable waste management and provides practical guidance for decision-makers. This integrated approach harmonizes environmental, economic, and social interests.

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