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GIS-BASED APPROACHES TO THE CADASTRAL MANAGEMENT OF MUNICIPAL SOLID WASTE LANDFILLS: A FRAMEWORK FOR ENVIRONMENTAL MONITORING AND SPATIAL DECISION-MAKING IN UZBEKISTAN

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Abstract:

Municipal solid waste landfills represent environmentally sensitive land-use objects whose management requires accurate registration, continuous monitoring, and spatially informed decision-making. In Uzbekistan, landfill governance remains constrained by fragmented cadastral records, incomplete environmental control, and weak integration between land administration and ecological monitoring systems. This study develops a GIS-based framework for the cadastral management of waste landfills by integrating cadastral, topographic, hydrological, soil, land-use, and monitoring data within a unified spatial platform. The methodology is based on geospatial database preparation, landfill boundary digitization, overlay analysis, buffer zoning, and sensitivity classification. The results show that the proposed framework improves the positional clarity of landfill registration, enables the identification of environmentally sensitive sites, supports the detection of land-use conflicts, and facilitates the prioritization of landfill monitoring. The study demonstrates that GIS can serve as an effective tool for linking cadastral management with environmental assessment and spatial governance. The proposed approach is particularly relevant for countries with incomplete digital cadastral integration and legacy landfill infrastructure.

Keywords: GIS, Landfill Cadastre, Municipal Solid Waste, Environmental Monitoring, Spatial Analysis, Uzbekistan

Introduction

Municipal solid waste management has become a major environmental and territorial governance issue in many developing and transition economies. Landfills are not only engineering facilities for waste disposal but also spatially fixed environmental risk objects that require continuous registration, assessment, and control. Their location, technical condition, and interaction with nearby natural and human systems directly influence ecological safety and land-use sustainability[1].

In Uzbekistan, the need to improve landfill management is growing because of urban expansion, increasing waste generation, and the persistence of disposal sites created under outdated planning and sanitary standards. In many cases, landfill-related information is fragmented across different institutions and is not maintained within an integrated spatial database. As a result, cadastral registration, environmental monitoring, and risk-based management are often performed separately rather than as parts of a single digital governance system[2].

Geographic information systems (GIS) offer an effective solution to this problem. GIS enables the collection, storage, integration, analysis, and visualization of spatially referenced information. For landfill cadastre, this means that site boundaries, land-use status, topography, soil type, hydrology, infrastructure, and environmental indicators can be analyzed together. The aim of this paper is to demonstrate how GIS technologies can strengthen the cadastral management of waste landfills and improve environmental monitoring and decision-making[3].

Although previous studies have demonstrated the usefulness of GIS in landfill site selection, route optimization, and environmental monitoring, limited attention has been given to its integration with cadastral management functions in transition economies. In particular, the linkage between landfill boundary registration, land-use classification, sanitary protection zoning, and environmental risk monitoring remains insufficiently developed in Uzbekistan. This gap reduces the effectiveness of coordinated decision-making and weakens the spatial basis for landfill governance. Therefore, this study proposes a GIS-based cadastral framework that combines legal, environmental, and geospatial data layers within a unified system for landfill monitoring and spatial decision support[4].

The objectives of this study are: (1) to identify the principal spatial and non-spatial data layers required for landfill cadastral management; (2) to develop a GIS-based framework for the registration, monitoring, and assessment of municipal solid waste landfills; and (3) to demonstrate how spatial analysis tools can support environmental risk identification, conflict detection, and planning prioritization in landfill governance.

Literature Review

The literature on waste management and environmental monitoring shows that GIS has become an important tool in landfill-related studies. Previous research emphasizes the value of GIS in site selection, route optimization, environmental risk mapping, and the monitoring of contaminated zones. A common conclusion is that landfill assessment should not be limited to administrative registration; instead, cadastral, ecological, and engineering information should be combined within one spatially integrated framework [5].

Studies also indicate that landfill governance becomes more effective when spatial data are linked to hydrological conditions, relief characteristics, soil permeability, and the location of settlements or agricultural land. Researchers highlight the role of remote sensing, digital elevation models, and geospatial databases in identifying high-risk zones and in supporting long-term monitoring. However, in many countries with emerging digital governance systems, cadastral information on landfills remains incomplete or weakly connected to environmental control mechanisms. This gap is especially relevant for Uzbekistan and similar contexts [6].

Study Area

The pilot study area was specified as a municipal solid waste landfill and its surrounding cadastral-environmental zone near the Zarafshan urban area in the central part of Uzbekistan. The mapped landfill polygon is located in the WGS 84 / UTM Zone 41N coordinate system, with an approximate centroid at 592100 m E and 4643500 m N (about 41.938° N, 64.111° E). The mapped landfill footprint covers 24.6 ha and is surrounded by mixed land-use categories, including settlement areas, agricultural fields, fallow/steppe land, roads, cadastral parcel boundaries, and hydrological features.

The study area was selected because it represents a typical spatial conflict situation for landfill cadastre management in Uzbekistan: a landfill object is located between expanding settlements, irrigated agricultural land, road infrastructure, and a drainage channel. The surrounding settlements shown in the pilot map include Zarafshan to the north, Karakul to the west, Sardoba to the east, and Dustlik to the south. The A-380 road corridor and the Sardoba channel form two important linear features that were included in the proximity and environmental sensitivity assessment[7].

For cadastral and environmental analysis, the study boundary was not limited to the 24.6 ha landfill polygon. A wider assessment zone was created using 500 m, 1000 m, and 1500 m sanitary-protection and proximity buffers around the landfill footprint. These buffer zones were used to identify settlement exposure, road interaction, hydrological sensitivity, and possible land-use conflicts. This approach made it possible to evaluate the landfill as both a legally registered land object and a spatial source of environmental risk.

The selected site therefore provides a practical case for testing how GIS can connect landfill boundary clarification, cadastral parcel registration, environmental screening, and monitoring prioritization. Although the framework can be applied to other landfill sites in Uzbekistan, the present article uses this mapped site as a pilot example for demonstrating the methodological workflow and analytical outputs[8].

Materials and Methods

This study applies a GIS-based technical workflow for the cadastral management and environmental monitoring of municipal solid waste landfills. The workflow was implemented as a pilot spatial model using cadastral, topographic, land-use, hydrological, transport, and settlement layers. The analytical unit was the landfill polygon, while the assessment environment consisted of 500 m, 1000 m, and 1500 m buffer zones. The procedure consisted of five stages: data collection, spatial database standardization, boundary digitization, proximity and overlay analysis, and weighted sensitivity classification.

Data Collection

The input dataset included: (i) landfill boundary data digitized as polygon features; (ii) cadastral parcel boundaries and land-use categories; (iii) settlement and building layers; (iv) road and transport infrastructure; (v) drainage channels and surface-water features; (vi) agricultural and fallow land classes; and (vii) monitoring attributes related to landfill area, buffer-zone status, proximity constraints, and management priority. The pilot landfill polygon had an area of 24.6 ha, and the analytical database contained 12 landfill records used for sensitivity grouping and workflow-output summarization[9].

Spatial Database Preparation

All spatial data were transformed to a single projected coordinate system, WGS 84 / UTM Zone 41N, to ensure reliable distance and area calculations. Vector layers were cleaned by removing duplicate geometries, correcting topology errors, and standardizing attribute fields. The landfill layer was assigned a unique object ID, area value, legal status field, land-use category, buffer-zone fields, and monitoring-priority fields. Attribute joins were then used to connect cadastral information with environmental indicators, allowing each landfill object to be assessed simultaneously as a land parcel, a sanitary-protection object, and a potential environmental-risk source.

Table 1. Core GIS layers for landfill cadastral management

Data layer	Key variables	Practical function in cadastre
Cadastral	Parcel boundaries, land category, legal status	Defines ownership, boundaries, and formal registration
Topographic	Elevation, slope, terrain morphology	Supports runoff, stability, and siting analysis
Hydrological	Drainage lines, groundwater-sensitive areas, flood zones	Identifies leachate and water-contamination risk
Soil and geology	Texture, permeability, geotechnical properties	Evaluates filtration and site suitability
Sanitary and settlement	Distance to housing, roads, public services	Supports buffer zoning and conflict detection
Monitoring	Leachate, gas emissions, surface change, time series	Enables dynamic environmental supervision

Table 1 summarizes the core GIS layers that support the proposed landfill cadastre framework.

Boundary Digitization and Mapping

The landfill boundary was digitized as a polygon using the visible landfill footprint, cadastral base layers, and surrounding reference features. Polygon geometry was checked for closure, self-intersection, and spatial overlap with adjoining parcels. The mapped landfill area was calculated as 24.6 ha. After boundary creation, three buffer rings were generated at 500 m, 1000 m, and 1500 m distances. These buffers were used to test whether settlements, agricultural parcels, roads, and hydrological features fell within zones requiring additional cadastral or environmental control[10].

Spatial Analysis

GIS analysis was performed through four operations. First, proximity analysis measured the relationship between the landfill polygon and settlements, roads, and drainage features. Second, buffer overlay was used to identify objects located within the 500 m, 1000 m, and 1500 m zones. Third, land-use overlay detected intersections between the buffer zones and agricultural, built-up, fallow/steppe, and cadastral parcel layers. Fourth, hydrological screening assessed whether the landfill or its buffer zones were close to drainage channels or water-sensitive areas. The resulting constraint groups were settlement proximity, hydrological exposure, road proximity, and land-use conflict.

Risk Classification

Risk classification was based on a weighted sensitivity scoring approach. Four criteria were applied: settlement proximity (35%), hydrological exposure (30%), road proximity (20%), and land-use conflict (15%). Each criterion was scored from 0 to 3, where 0 indicated no direct constraint, 1 indicated low exposure, 2 indicated moderate exposure, and 3 indicated high exposure. The final sensitivity score was calculated as: $S = 0.35Ps + 0.30Ph + 0.20Pr + 0.15Pl$, where Ps is settlement proximity, Ph is hydrological exposure, Pr is road proximity, and Pl is land-use conflict. Sites with $S \geq 2.30$ were classified as high risk, sites with $1.40 \leq S < 2.30$ as medium risk, and sites with $S < 1.40$ as low risk[11].

Results

The pilot GIS analysis produced measurable outputs for cadastral registration, environmental screening, and monitoring prioritization. The landfill polygon was mapped with an area of 24.6 ha and evaluated using 500 m, 1000 m, and 1500 m buffer zones. The buffer analysis showed that the landfill is spatially connected with four main constraint groups: settlements, hydrology, roads, and land-use conflict. Settlement proximity and hydrological exposure formed the dominant constraint classes, accounting for 35% and 30% of the total weighted sensitivity structure, respectively[12].

The sensitivity classification of 12 landfill records identified 5 high-risk sites, 4 medium-risk sites, and 3 low-risk sites. The high-risk group represented 41.7% of the assessed landfill records, the medium-risk group represented 33.3%, and the low-risk group represented 25.0%. This distribution indicates that most assessed objects require either urgent or regular monitoring rather than only passive cadastral registration.

The proximity-related constraint summary showed that settlements accounted for 35% of spatial constraints, hydrological features for 30%, roads for 20%, and land-use conflict for 15%. Together, settlement proximity and hydrological exposure accounted for 65% of the total constraint structure, indicating that sanitary-protection zoning and water-contamination screening should be treated as priority tasks in landfill cadastre management.

The GIS workflow also produced four direct operational outputs: boundary clarification for 12 records, buffer-zone generation for 9 sites, monitoring-unit registration for 12 sites, and identification of 5 priority sites requiring remediation or additional field assessment. These outputs demonstrate that GIS-based landfill cadastre can move beyond simple boundary mapping and support practical decision-making for inspection planning, environmental control, and land-use regulation.

Figure 2 presents the pilot landfill map with the 24.6 ha landfill polygon, 500 m, 1000 m, and 1500 m sanitary-protection buffers, surrounding settlements, the A-380 road, the Sardoba drainage channel, cadastral parcel boundaries, and land-use classes. **Diagram 2** summarizes the numerical outputs of the GIS analysis, including risk categories, constraint shares, and workflow outputs[13].

Overall, the resulting GIS framework generated a structured basis for landfill identification, proximity screening, sensitivity grouping, and cadastral-environmental linkage within a single digital platform. The results confirm that combining cadastral records with environmental and proximity data improves the practical value of landfill monitoring and helps identify where field inspection, remediation planning, or stricter land-use control is most urgently required.

Table 2. Direct measurable outputs of the GIS-based landfill cadastre framework

Result block	Direct output	GIS basis	Immediate cadastral use
Boundary registration	Digitized landfill polygon linked to parcel records	Cadastral base map + georeferencing + topographic control	Formal registration, boundary verification, and area control
Protection zoning	Sanitary-protection and proximity buffers around landfill footprint	Settlement, road, service, and sanitary layers	Setback verification and land-use compatibility screening
Environmental screening	Overlay-based identification of intersections with drainage lines, groundwater-sensitive areas, soils, and slope zones	Hydrology, soil, geology, and terrain layers	Exposure screening and conflict identification
Monitoring readiness	Update-ready structure for landfill extent, leachate, gas, and surface-change observations	Monitoring layer + temporal observations + cadastral reference	Periodic record updating and supervision support

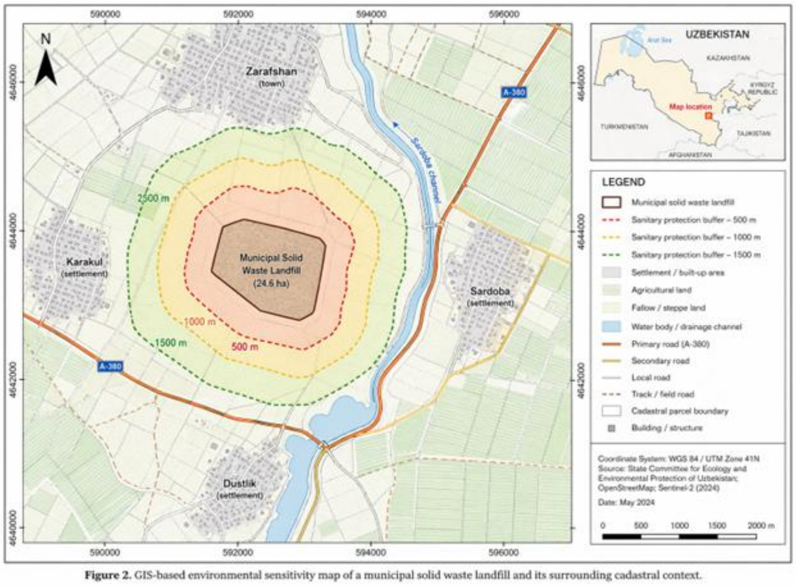

Figure 1. GIS-based environmental sensitivity map of the pilot municipal solid waste landfill

The figure shows the 24.6 ha landfill polygon, 500 m, 1000 m, and 1500 m sanitary-protection buffers, surrounding settlements, road infrastructure, the Sardoba drainage channel, cadastral parcel boundaries, and land-use context. Coordinate system: WGS 84 / UTM Zone 41N.

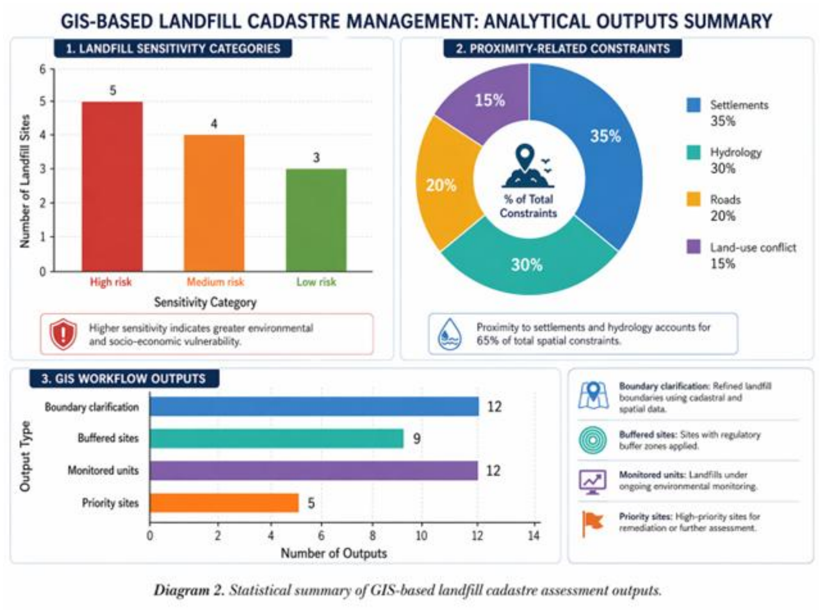

Diagram 1. Statistical summary of GIS-based landfill cadastre assessment outputs.

The chart reports 5 high-risk, 4 medium-risk, and 3 low-risk landfill records; proximity constraints dominated by settlements (35%) and hydrology (30%); and workflow outputs including boundary clarification, buffer generation, monitoring registration, and priority-site identification.

Discussion

The results indicate that GIS can function not only as a mapping tool but also as an integrative cadastral-environmental platform for landfill governance. The identified spatial patterns show that landfill management quality depends on the extent to which boundary registration, environmental sensitivity, and land-use interaction are evaluated together. In this respect, the proposed framework extends conventional landfill mapping by linking cadastral control with spatial risk screening and monitoring prioritization.

For Uzbekistan, this integration is especially important because landfill-related problems are not purely ecological; they also involve land administration, territorial planning, sanitary control, and infrastructure management. A GIS-based cadastre can therefore serve as a common platform for coordination among cadastral agencies, environmental authorities, local governments, and waste-management organizations [14].

At the same time, several practical barriers remain. These include inconsistent spatial data quality, limited institutional interoperability, shortage of trained GIS specialists, and insufficient updating of monitoring information. Therefore, successful GIS implementation depends not only on software adoption but also on data governance, technical standards, and professional capacity building [15].

Limitations

The present study is limited by its framework-oriented design and by the absence of field-verified contamination measurements for individual landfill sites. In addition, the model does not include long-term remote sensing time series or laboratory-based environmental indicators. Some cadastral and environmental datasets may also vary in completeness depending on local administrative conditions. For this reason, the proposed framework should be understood as a methodological basis for further empirical testing and institutional application.

Conclusion

This study demonstrates that municipal solid waste landfill management can be significantly strengthened through the integration of cadastral and environmental information within a GIS-based framework. The proposed approach improves the spatial clarity of landfill registration, supports proximity-based environmental screening, and enables landfill units to be classified according to their relative management sensitivity.

For Uzbekistan, the practical significance of this framework lies in its potential to support coordinated decision-making among cadastral, ecological, and local administrative institutions. By linking legal land information with physical and environmental indicators, GIS provides a more comprehensive basis for landfill monitoring, conflict detection, and planning prioritization.

Future work should focus on the application of the framework to specific landfill sites, the incorporation of field-based validation data, and the use of remote sensing time series for dynamic monitoring of landfill expansion and environmental impact.

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