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Article

Multicriteria Model for Selection of Landfill Site for Solid Waste in the Municipality of Arbiето

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Abstract: In many developing countries, especially in rural areas, municipal solid waste is still disposed of in open dumps without proper environmental or technical controls. This situation poses serious public health and environmental risks. The municipality of Arbiето, Bolivia, currently lacks an engineered landfill and manages its waste through a reconditioned dumpsite with limited infrastructure and no systematic planning. This study aims to propose a technically and environmentally sound solution for final waste disposal by identifying suitable sites for a sanitary landfill. A multi-criteria spatial analysis was conducted using Geographic Information System (ArcGIS) tools, considering factors such as slope, hydrology, land use, vegetation cover, and distance from populated areas. The General Algebraic Modeling System (GAMS) was applied to optimize the transport network from 20 waste generation points to the selected site. The methodological design is informed by best practices from international studies that applied GIS and AHP for landfill siting. The results showed that 7.63% of the territory is highly suitable, 27.84% moderately suitable, and 29.06% not suitable. The analysis confirms that Arbiето has technically viable areas for sanitary landfill development. The study recommends implementing a controlled, sustainable disposal strategy based on spatial planning and international technical standards.

Keywords: sanitary landfill; site selection; GIS; GAMS; solid waste management; Bolivia; multi-criteria analysis

1. Introduction

The final disposal of municipal solid waste (MSW) remains a major environmental and public health challenge in many rural and peri-urban areas of developing countries, where open dumpsites continue to be the only management solution. In Bolivia, this issue is evident in several municipalities that lack technical infrastructure and comprehensive planning for the safe treatment and elimination of waste [1,2]. The municipality of Arbiето, located in the department of Cochabamba, exemplifies this problem: it comprises 67 communities, yet only the central town in District 1 has a reconditioned dumpsite, which operates without proper control of leachate or gas emissions. The remaining communities lack collection systems and typically resort to burning or burying waste [3], practices that increase soil and water pollution and directly affect public health.

In response to this situation, it is crucial to implement a sustainable strategy for final disposal site selection that integrates environmental, social, legal, and technical criteria. Various international studies have demonstrated the effectiveness of Geographic Information Systems (GIS) and multi-criteria analysis (MCA) in identifying optimal locations for sanitary landfills. For example, Bera et al. [2] used spatial overlays of variables such as slope, geology, and land use in India; Ampofo et al. [3] applied GIS integrated with the Analytic Hierarchy Process (AHP) in Ghana to avoid social conflict zones; Barros et al. [1] utilized Boolean logic and map algebra in Brazil to comply with environmental legislation; similarly, Quinteros et al. [6] in Bolivia, Biazen Molla [7] in Ethiopia, and Arabeyyat et al. [8] in Jordan demonstrated the usefulness of GIS-based multicriteria evaluation for landfill siting in diverse environmental and social contexts.

In this context, the present study aims to determine the most suitable site for the final disposal of municipal solid waste in Arbiето by applying a spatial multi-criteria analysis using GIS and an optimization model with GAMS software. The working hypothesis is that the integrated use of these tools enables the identification of technically feasible, environmentally safe, and socially acceptable landfill sites, offering a replicable approach for other rural municipalities.

The results indicate that there are areas with high territorial suitability for constructing a sustainable sanitary landfill in Arbiето. This solution could significantly reduce soil and water contamination, improve public health, and align with sustainable development goals through an approach that combines technical, environmental, and social dimensions.

2. Materials and Methods

This study implemented a geospatial multicriteria decision-making (MCDM) methodology using ArcGIS to identify optimal locations for sanitary landfill siting in the municipality of Arbiето, Cochabamba, Bolivia. The method integrates environmental, technical, legal, and social criteria in a Boolean logic overlay model, ensuring equal weight for all variables.

2.1. Review of Technologies and Planning Approaches

To contextualize the proposed methodology, a literature review was conducted, focusing on best practices for siting landfills using Geographic Information Systems (GIS), multicriteria evaluation, and alternative disposal technologies. Key studies included landfill planning strategies using AHP and GIS (Barros et al. [1]), weighted overlay mapping (Bera et al. [2]), and multicriteria evaluation in African contexts (Ampofo et al. [3]). Additional examples of landfill siting using multicriteria methods in Bolivia and other developing countries were also reviewed (Quinteros et al. [6], Biazen Molla [7], Arabeyyat et al. [8]). Furthermore, recent advances in leachate treatment and waste valorization strategies were considered (Cheniti et al. [4], Kerboua et al. [5]).

2.2. Study Area and Data Collection

The municipality of Arbiето comprises seven districts and 67 communities. Data layers were acquired from the PTDI of Arbiето and the Instituto Geográfico Militar (IGM). The following shapefiles were used:

- Digital Elevation Model (DEM)
- Hydrography (rivers and water bodies)
- Road network (secondary and tertiary)
- Urban and rural population centers
- Geological formations
- Vegetation cover (classified from Landsat imagery)

Figure 1 shows the shapefile of the Map of the Municipality of Arbiето inserted into the ArcGIS software, as the starting point for adding the other shapefiles required for the multicriteria model for sanitary landfill site selection.

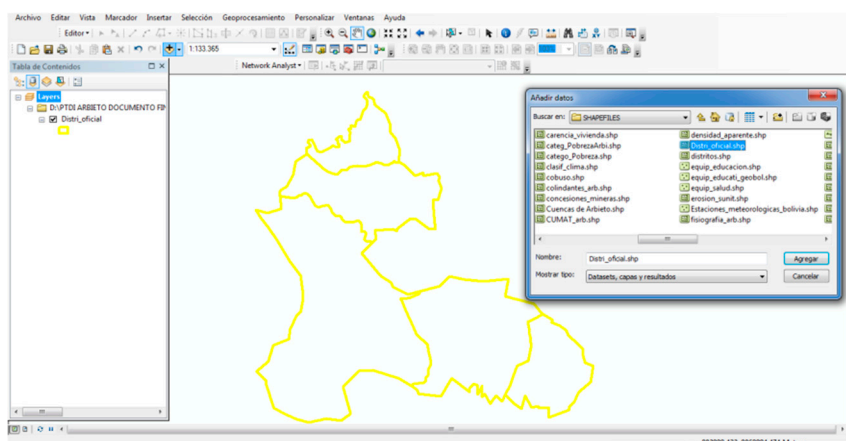
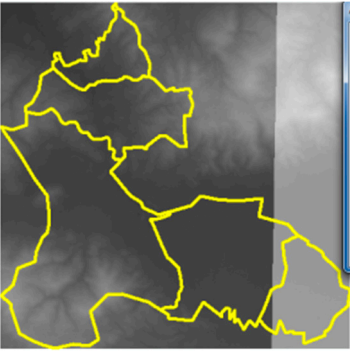


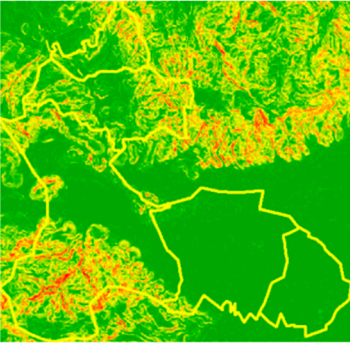
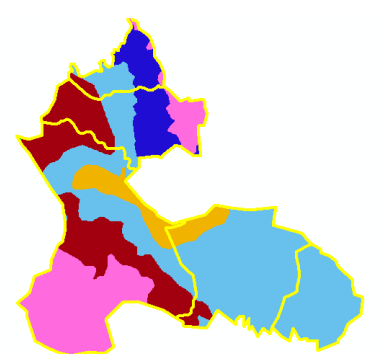
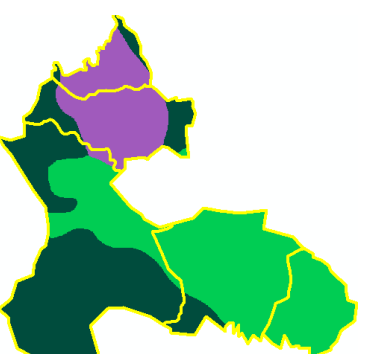



Figure 1. Map of the Municipality of Arbiesto in ArcGIS Software. Source: Author's elaboration.

Table 1 presents the maps and shapefiles required to apply the Multicriteria Model for the selection of a final disposal site for municipal solid waste.

Table 1. Maps and shapefiles required for applying the Multicriteria Model for final disposal site selection of solid waste.

DEM Digital Elevation Model	Hydrography Map derived from DEM	Road Network Shapefile
		
Slope Map generated from DEM	Vegetation Cover Shapefile	Geology Shapefile
		
Shapefile of Population Centers	Colors:	Colors:

	<p>Brown 51 = Lower semi-arid prepuna forest of the Río Grande basin.</p> <p>Green 129 = Montane dry forest, Bolivian-Tucuman and northern prepuna.</p> <p>Blue 1659 = Lower semi-arid prepuna forest of the Río Grande basin.</p> <p>Light blue 1680 = Anthropogenic: extensive crops, fallow lands, and extensive grasslands + p24b = Phreatophytic forests of the Central Prepuna + p25b = Riparian vegetation of the Central Prepuna + p27 = No vegetation.</p> <p>Yellow 1682 p27 = No vegetation.</p> <p>Pink 1776 = High-mountain grasslands (CES409.218, CES409.219) and montane and high-mountain scrublands (CES409.212, CES409.213); and saxicolous vegetation of the Bolivian-Tucuman Montane Edge.</p>	<p>S purple = Silurian Shales, siltstones, quartzites, and diamictites</p> <p>Q green = Quaternary Alluvial, fluviolacustrine, fluvioglacial, colluvial, lacustrine, moraine, and dune deposits</p> <p>Ng orange = Neogene Conglomerates, sandstones, claystones, gypsums, marls, tuffs, interbedded lavas, and diapirs</p> <p>O dark green = Ordovician Sandstones, siltstones, quartzites, slates, shales, and pillow lavas</p>
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Source: Author's elaboration.

2.3. Multicriteria Criteria and Processing in ArcGIS

Six critical variables were defined: slope, distance to rivers, distance to roads, distance to settlements, geology, and vegetation cover. Each layer was standardized and reclassified into binary values: 1 = suitable, 0 = unsuitable. Suitability thresholds were defined based on Bolivian technical norms and international literature:

C_1 : Slope: Areas with a slope between 4° and 15° were considered suitable.

C_2 : Hydrology: A buffer of 500 m was applied to all surface water bodies to avoid contamination.

C_3 : Road Access: Sites located more than 500 m from main roads were favored, balancing access and impact mitigation.

C_4 : Proximity to Settlements: A minimum distance of 500 m from populated centers was established to prevent health risks.

C_5 : Geology: Stable, low-permeability geological formations were preferred.

C_6 : Land Cover: Areas without significant vegetation or agricultural activity were prioritized.

$$C_i(x, y) = \begin{cases} 1 & \text{if criterion } i \text{ is satisfied at location } (x, y) \\ 0 & \text{if not satisfied} \end{cases}$$

where $C_i(x, y)$ is the value of criterion i at the spatial point (x, y)

Table 2. Criteria for Sanitary Landfill Site Selection.

Criterion 1: Slope	Criterion 2: Hydrology	Criterion 3: Access Roads	Criterion 4: Population Centers	Criterion 5: Vegetation Cover	Criterion 6: Geology	Value
<15°	>500 m	>500 m	>500 m	Fam. Apacheta, Condorsinga, Cercapuquio, Volcanic Center, Antarazo, Subvolcanic Rocks, Andesite/Diabase, Dacite/Rhyodacite, Fam. Astobamba, Chambara, Sacsaquero, Castrovirreyna.	Area without vegetation, semi-humid scrubland, humid scrubland, grassland.	1
>15°	<500 m	<500 m	<500 m	Fam. Chulec-Pariatambo, Chayllacatana, Goyllarisquisga, Casapalca, Auquivilca, Caudalosa, Huando, Huichinga, Santa Barbara, Andesite/Diabase, Apacheta, Wetland Deposits, Glaciers, Urban Areas.	Urban areas, wetlands, agricultural cultivation areas, glaciers, lakes, rivers, forest plantations.	0

Source: Own elaboration based on GEO GISS [9].

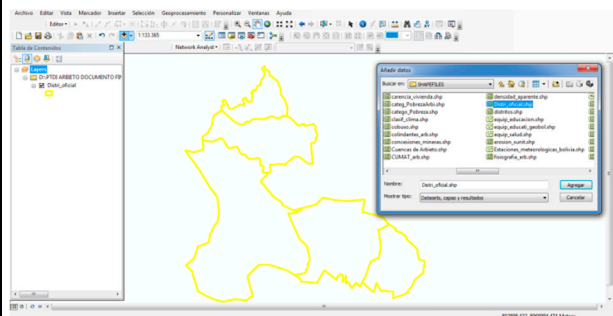
The final suitability $S(x, y)$ is obtained through the logical intersection of all considered criteria. Each spatial layer was transformed into a binary map (1 = meets the criterion, 0 = does not meet the criterion) using ArcGIS tools such as Slope, Euclidean Distance, Reclassify, and Raster Calculator. Layers were combined using a Boolean overlay method. The final suitability was calculated as:

$$S(x, y) = C_1(x, y) \wedge C_2(x, y) \wedge \dots \wedge C_n(x, y)$$

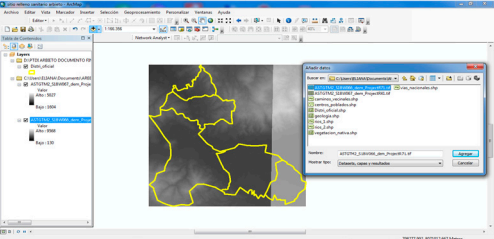
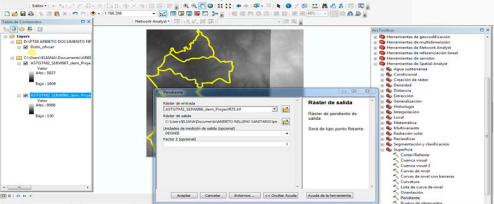
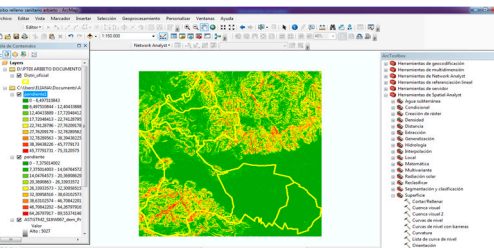
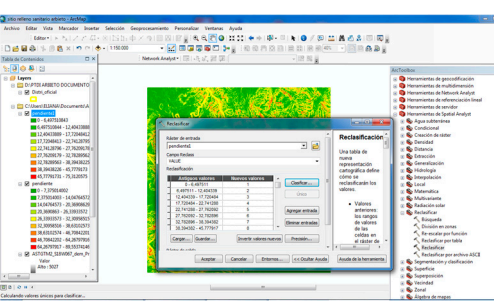
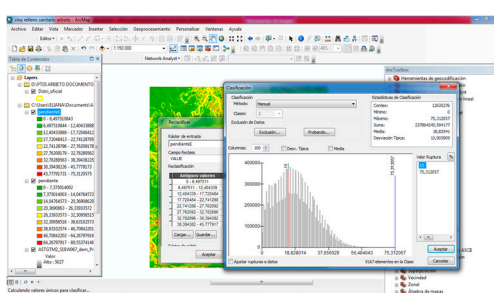
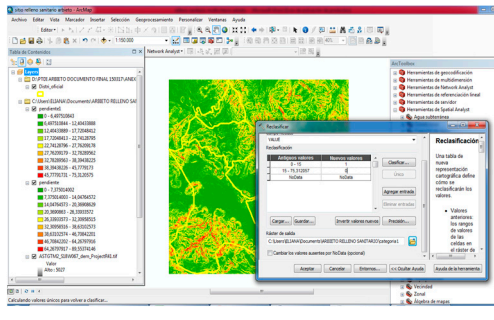
A final value of $S(x, y) = 1$ indicates that the location is suitable for final disposal according to all criteria, while a single value of 0 in any layer excludes the site.

where $S(x, y)$ represents the final suitability at point (x, y) and C_i are the binary criteria. Only cells with a value of 1 in all layers were considered suitable.

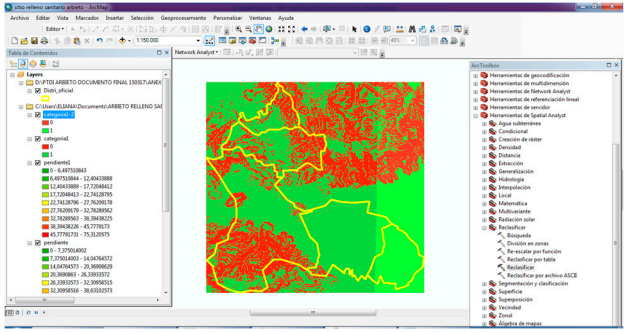
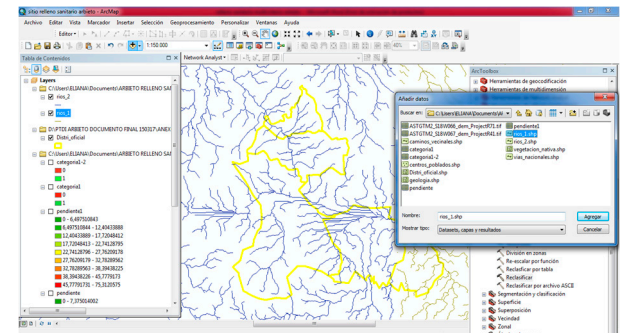
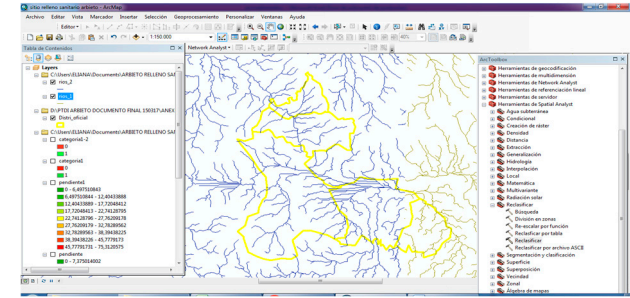
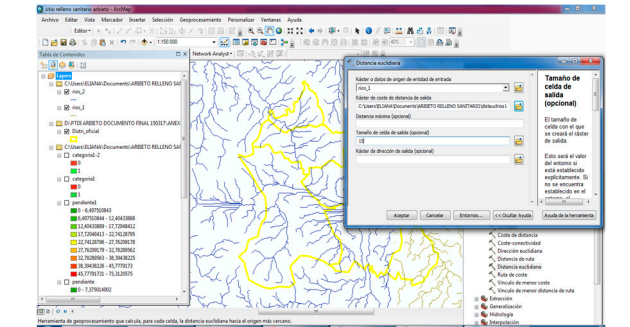
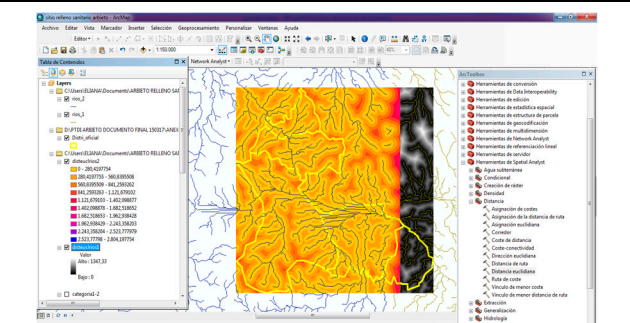
Table 3. Procedure for Sanitary Landfill Site Selection Using the Multicriteria Model.

ARCGIS MULTICRITERIA MODEL FOR SANITARY LANDFILL			
No	Procedure	Tool	Window
1	First, the georeferenced map of the Municipality of Arbieto is imported into ArcGIS software.	Add Data > Shapefile Distri_oficial	

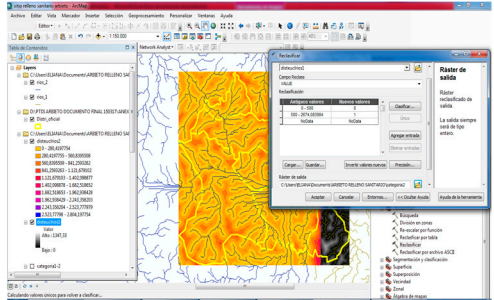
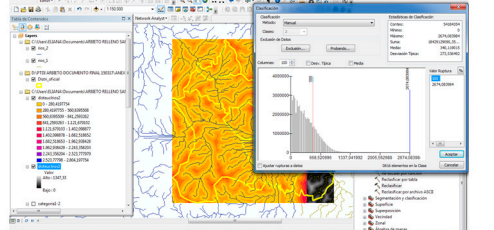
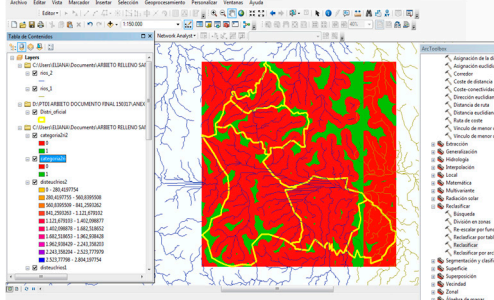
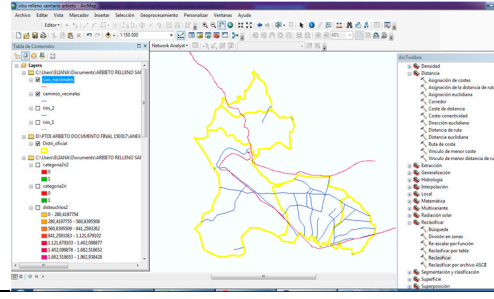
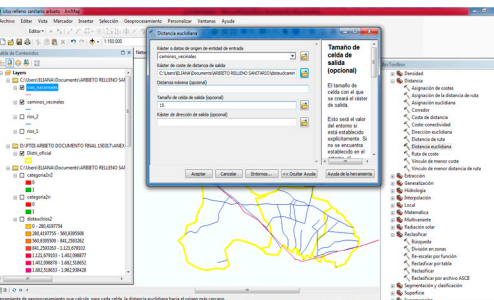
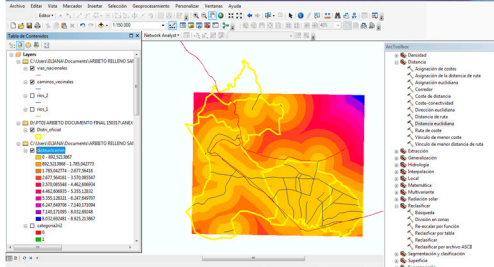
ARCGIS MULTICRITERIA MODEL FOR SANITARY LANDFILL

No	Procedure	Tool	Window
2	Subsequently, the Digital Elevation Model (DEM) of the Municipality is imported into ArcGIS software to proceed with slope determination.	Add Data > DEM ASTGTM2_S18W066 DEM ASTGTM2_S18W067	
3	Once the DEM is imported, the slope map is generated.	ArcToolbox > Spatial Analyst Tools > Surface > Slope > Input raster: DEM	
4	The slope map result is presented.		
5	Tool for reclassification of the slope map with ranges: 0–15%, >15%	ArcToolbox > Spatial Analyst Tools > Reclassify > Reclassify	
6	Reclassification of slopes of 15% and greater	Input Raster: Slope > Classify > Classification Method: Equal Interval > Classes: 2 > Break Value: 15%	
7	Assignment of values for the slope criterion	Old Values: 0–15 → New Value: 1 Old Values: >15 → New Value: 0	

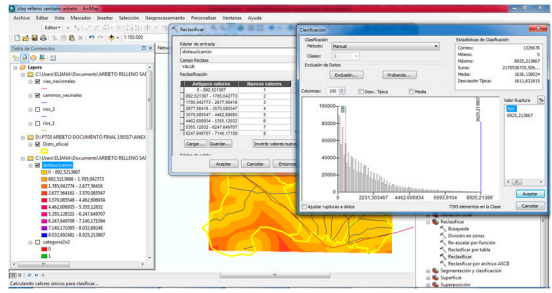
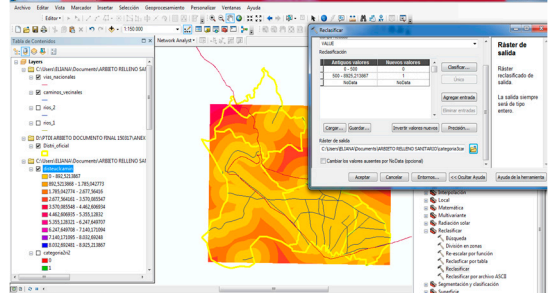
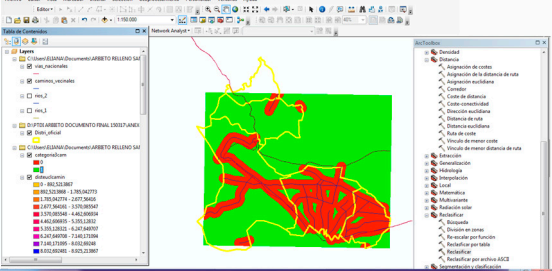
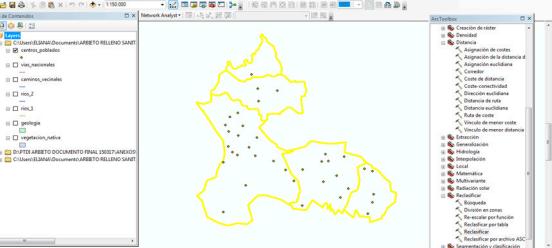
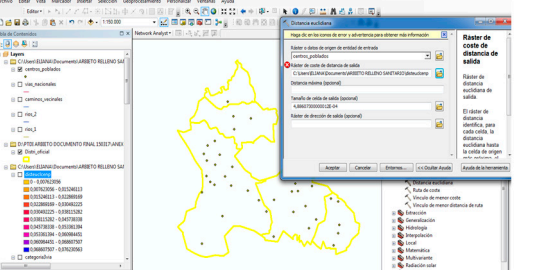
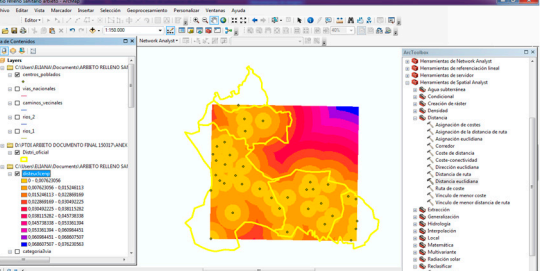
ARCGIS MULTICRITERIA MODEL FOR SANITARY LANDFILL

No	Procedure	Tool	Window
8	Category 1: Slopes 0–15%: Green color, value = 1 15%: Red color, value = 0		
9	Insertion of the shapefile for rivers in the Municipality of Arbieto	Add Data > Shapefile Rivers	
10	River Map		
11	Euclidean Distance from Rivers in the Municipality of Arbieto	Tool: ArcToolbox > Spatial Analyst Tools > Distance > Euclidean Distance Input Raster: Shapefile Rivers	
12	Generated Euclidean Distance Map for Rivers		

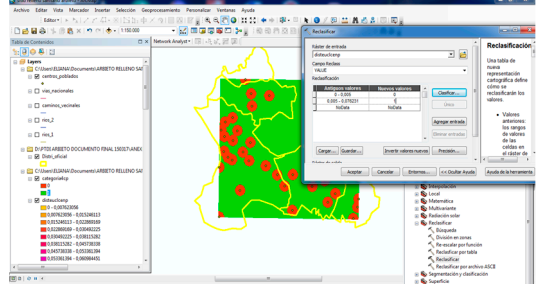
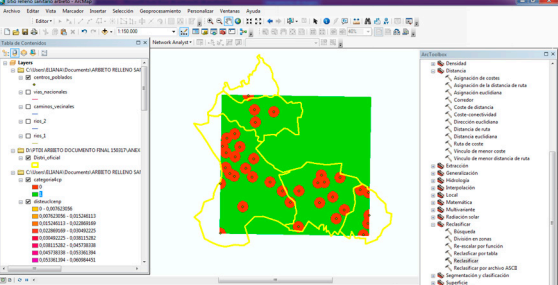
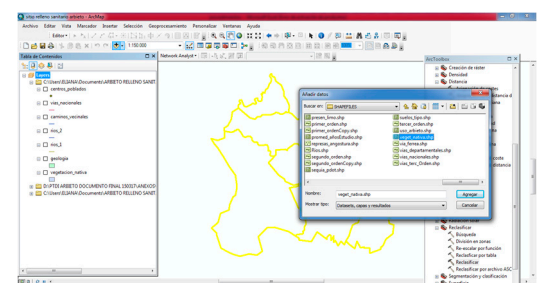
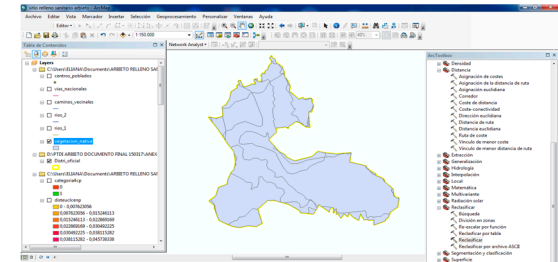
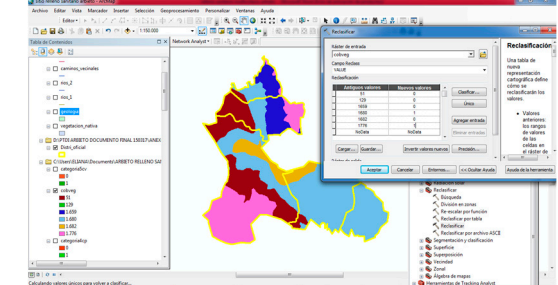
ARCGIS MULTICRITERIA MODEL FOR SANITARY LANDFILL

No	Procedure	Tool	Window
13	Generation of Reclassified Distance Map to Rivers with Ranges: 0–500 m, >500 m	Tool: ArcToolbox > Spatial Analyst Tools > Reclassify > Input Raster: Euclidean Rivers Classification Method: Equal Interval Number of Classes: 2 Break Value: 500 m	
14	Assignment of Values for the Rivers Criterion	Old Values: 0–500 m → New Value: 1 Old Values: >500 m → New Value: 0	
15	Categoría 2: Ríos, Category 2: Rivers 0–500 m: Color verde valor 1, >500 m.: Color rojo valor 0.	0–500 m: Green (Value = 1) >500 m: Red (Value = 0)	
16	Insertion of Road Shapefile from the Municipality of Arbioto	Tool: Add Data > Shapefile Local Roads	
17	Euclidean Distance for Roads in the Municipality of Arbioto	Tool: ArcToolbox > Spatial Analyst Tools > Distance > Euclidean Distance Input Raster: Shapefile Local Roads	
18	Generation of Euclidean Distance Map for Roads		

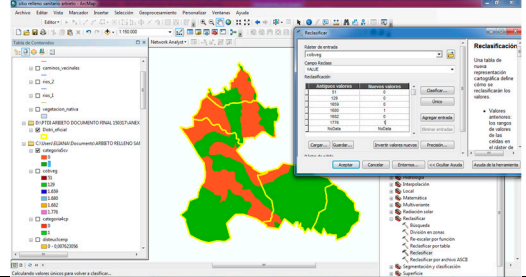
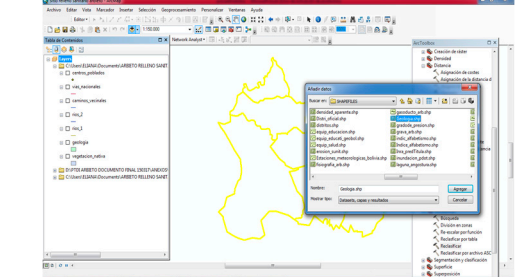
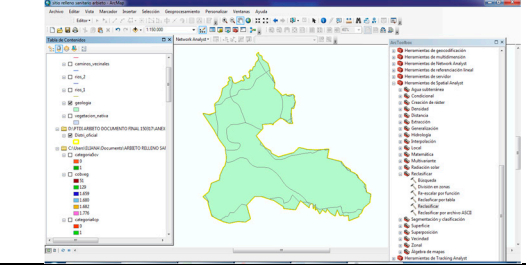
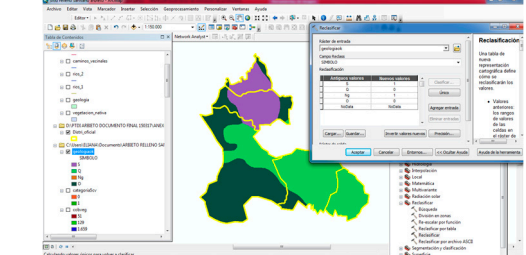
ARCGIS MULTICRITERIA MODEL FOR SANITARY LANDFILL

No	Procedure	Tool	Window
19	Generation of reclassified distance map to roads with ranges: 0–500 m, >500 m	Tool: ArcToolbox > Spatial Analyst Tools > Reclassify Input Raster: Euclidean Distance to Roads Classification Method: Equal Interval Classes: 2 Break Value: 500 m	
20	Assignment of Values for the Roads Criterion	Old Values: 0–500 → New Value: 1 Old Values: >500 → New Value: 0	
21	Category 3: Roads 0–500 m: Green (Value = 1); >500 m: Red (Value = 0)		
22	Insertion of Urban Center Shapefile from Arbiesto Municipality	Tool: Add Data > Shapefile Localities	
23	Euclidean Distance from Urban Centers in Arbiesto	Tool: ArcToolbox > Spatial Analyst Tools > Distance > Euclidean Distance Input Raster: Shapefile Localities	
24	Generation of Euclidean Distance Map for Urban Centers		

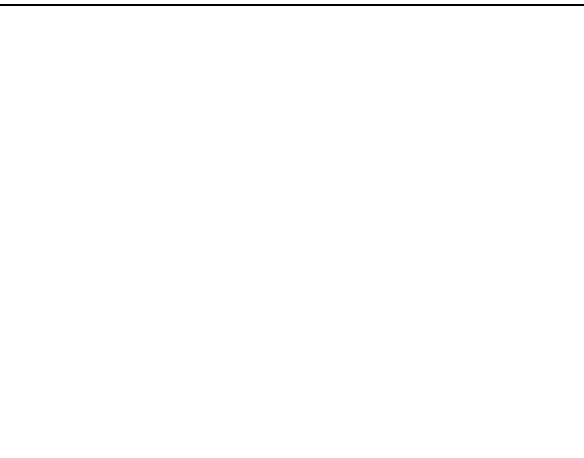
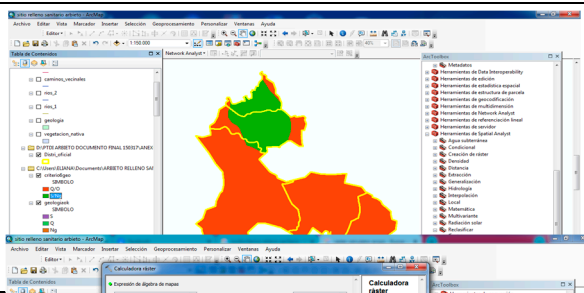
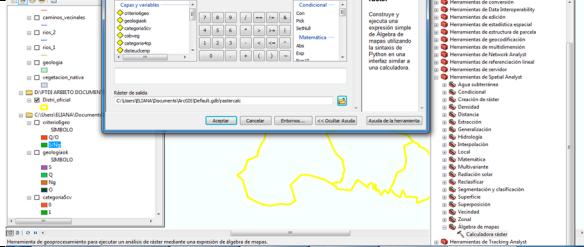
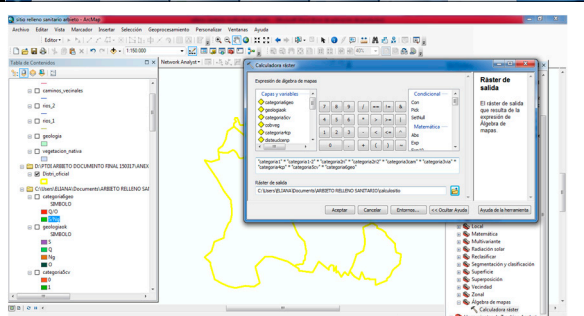
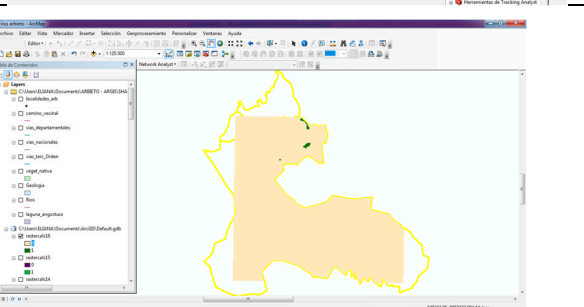
ARCGIS MULTICRITERIA MODEL FOR SANITARY LANDFILL

No	Procedure	Tool	Window
25	Reclassified distance map to urban centers with ranges: 0–500 m, >500 m	Tool: ArcToolbox > Spatial Analyst Tools > Reclassify Input Raster: Euclidean Localities Classification Method: Equal Interval Classes: 2 Break Value: 500 m	
26	Assignment of Values for the Urban Centers Criterion	Old Values: 0–500 → New Value: 1 Old Values: >500 → New Value: 0	
27	Category 4: Urban Ce0–500 m: Green (Value = 1); >500 m: Red (Value = 0)nters		
28	Insertion of Vegetation Cover Shapefile for Arbieto Municipality	Tool: Add Data > Shapefile Native Vegetation	
29	Vegetation Cover Map		
30	Reclassification of Vegetation Cover Map	Tool: ArcToolbox > Spatial Analyst Tools > Reclassify Input Raster: Native Vegetation Rasterized by FID	

ARCGIS MULTICRITERIA MODEL FOR SANITARY LANDFILL

No	Procedure	Tool	Window
31	Assignment of Values for the Vegetation Criterion	Old Values: 1776: Grasslands, shrublands (montane and high montane), saxicolous vegetation 1680: Anthropogenic, extensive crops, fallows, grasslands, phreatophytic forests, riparian vegetation = New Value: 1 1659: Forest, 51: Lower forest, 1682: No vegetation (Laguna Angostura area) = New Value: 0	
32	Category 5: Vegetation Cover. Green Color: Value = 1; Red Color: Value = 0		
33	Insertion of Geology Shapefile for Arbieto Municipality	Tool: Add Data > Shapefile Geology	
34	Geology Map		
35	Reclassification of Geology Map	Tool: ArcToolbox > Spatial Analyst Tools > Reclassify Input Raster: Geology Rasterized by Symbol	

ARCGIS MULTICRITERIA MODEL FOR SANITARY LANDFILL

No	Procedure	Tool	Window
36	Assignment of Values for the Geology Criterion	Old Values: "S": shales, siltstones, quartzites, diamictites = New Value: 1 "Q": alluvial, lacustrine, colluvial deposits, etc. "Ng": conglomerates, sandstones, clays, gypsum, etc. "O": sandstones, quartzites, slates, pillow lavas = New Value: 0	
37	Category 6: Geology Green Color: Value = 1; Red Color: Value = 0		
38	Map Calculator	Tool: ArcToolbox > Spatial Analyst Tools > Map Algebra	
39	Final Sanitary Landfill Site Suitability Calculation	Formula: Final Site = Criterion 1 \wedge Criterion 2 \wedge Criterion 3 \wedge Criterion 4 \wedge Criterion 5 \wedge Criterion 6	
40	Final Map of Sanitary Landfill Site		

Source: Author's elaboration.

2.4. Model Workflow

Importation of shapefiles (DEM, roads, rivers, settlements, geology, vegetation)

Generation of slope layer (Slope tool)

Euclidean Distance for rivers, roads, and settlements
Reclassification into binary raster layers (Reclassify tool)
Raster overlay via Raster Calculator to generate final suitability map
Exportation of final map in raster and shapefile formats for validation and visualization.

2.5. Optimization with GAMS

To complement spatial analysis, the General Algebraic Modeling System (GAMS) was used to optimize transportation routes and costs from 20 waste generation sources. The optimization function minimized operational and environmental costs, facilitating efficient allocation of resources for future landfill management.

2.6. Validation

The methodology was validated based on prior applications in rural or peri-urban areas of Brazil [1], India [2], and Ghana [3], demonstrating replicability in contexts with limited access to high-resolution datasets.

2.7. Declaration of AI Use

No generative artificial intelligence (GenAI) was used in the generation of data, analysis, or interpretation. AI tools were used only for editing and proofreading support.

2.8. Data Availability

All spatial layers used in this study are publicly available through the PTDI of Arbiesto and the Instituto Geográfico Militar (IGM). DEM data were obtained from ASTGTM2 tiles S18W066 and S18W067.

2.9. Ethical Considerations

This study did not involve human or animal subjects and therefore did not require ethical approval. The approach outlined ensures transparency, replicability, and adaptability to other municipalities with similar territorial and institutional constraints.

3. Results

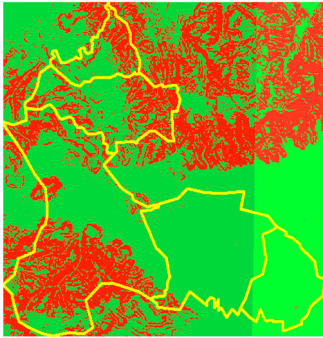
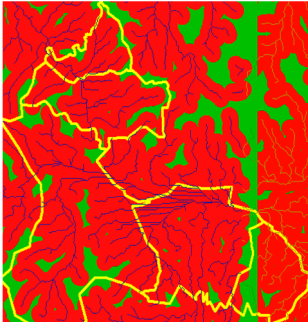
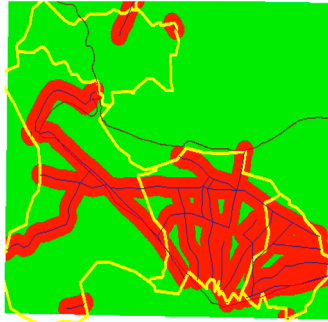
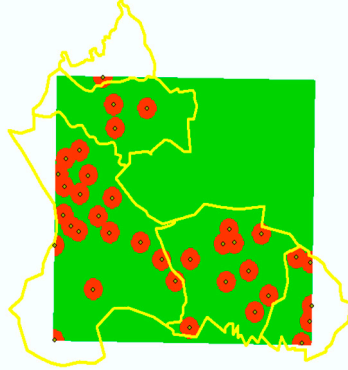
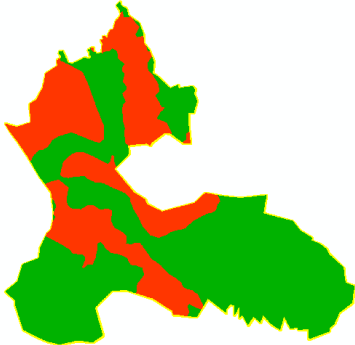
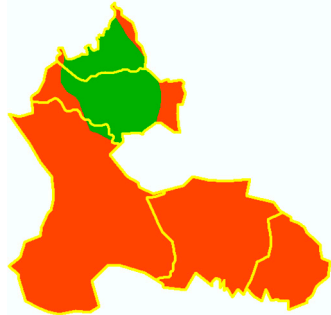
This section presents the results of the multicriteria model developed for the sanitary landfill site selection in the Municipality of Arbiesto, Cochabamba, using ArcGIS software.

3.1. Individual Criterion Mapping

The multicriteria analysis evaluated six critical factors: slope, proximity to rivers, proximity to roads, proximity to settlements, vegetation cover, and geological stability. Each factor was processed into binary suitability layers (1 = suitable; 0 = unsuitable) according to defined thresholds.

Table 4 summarizes the classification criteria for each variable.

Table 4. Criteria Results for Sanitary Landfill Site Selection.

Criterion 1: Slope	Criterion 2: Hydrography	Criterion 3: Roads
		
Value 1: Green color – Slope: 0–15% Value 0: Red color – Slope: >15%	Value 1: Green color – Rivers: >500 m Value 0: Red color – Rivers: 0–500 m	Value 1: Green color – Roads: >500 m Value 0: Red color – Roads: 0–500 m
Criterion 4: Settlements	Criterion 5: Vegetation Cover	Criterion 6: Geology
		
Value 1: Green color – Urban centers located more than 500 m away Value 0: Red color – Urban centers located within 0–500 m	Value 1: Green color – Suitable areas: grasslands, shrublands (montane and high-mountain), saxicolous vegetation, anthropogenic zones, extensive crops, fallow lands, extensive meadows, phreatophytic forests, and riparian vegetation of the central Prepuna (i.e., areas with no significant vegetation). Value 0: Red color – Unsuitable areas: dense forests, lower Prepuna forests, and zones with no vegetation near the Angostura lagoon.	Value 1: Green color – Suitable geology: shales, siltstones, quartzites, and diamictites. Value 0: Red color – Unsuitable geology: alluvial, fluvio-lacustrine, fluvio-glacial, colluvial, lacustrine deposits, moraines, dunes; Neogene conglomerates, sandstones, claystones, gypsums, marls, tuffs, interbedded lavas and diapirs; Ordovician sandstones, siltstones, quartzites, slates, shales, and pillow lavas.

Source: Author's elaboration.

Criterion 1. Slope: Areas with slopes $<15^\circ$ were classified as suitable (green, value = 1); areas $>15^\circ$ as unsuitable (red, value = 0).

Criterion 2. Distance to rivers: >500 m suitable (green); <500 m unsuitable (red).

Criterion 3. Distance to roads: >500 m suitable (green); <500 m unsuitable (red).

Criterion 4. Distance to settlements: >500 m suitable (green); <500 m unsuitable (red).

Criterion 5. Vegetation cover: disturbed land, shrublands, and grasslands considered suitable (green); forests and wetlands unsuitable (red).

Criterion 6. Geology: stable formations with low permeability were suitable (green); permeable or unstable formations were unsuitable (red).

3.2. Final Suitability Mapping

The final suitability map was obtained by applying a Boolean intersection of all criteria layers. These criteria were integrated into a single Boolean overlay model using the following equation, as described by Equation (1):

$$S(x, y) = C_1(x, y) \wedge C_2(x, y) \wedge \dots \wedge C_n(x, y)$$

where $S(x, y)$ represents the final suitability at location (x, y) , and each C_i is a binary criterion layer.

Only cells satisfying all criteria (value = 1) were selected as suitable landfill sites.

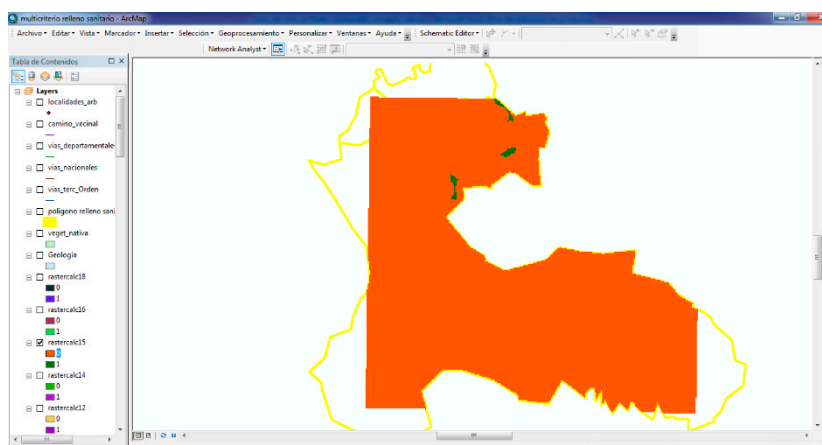


Figure 2. Final suitability map identifying optimal landfill locations (ArcGIS raster output). Source: Author's elaboration.

In Figure 3, the results of the final solid waste disposal site selection are presented using a satellite map. This visual representation illustrates the optimal zones identified through the multicriteria model, highlighting suitable areas for the future sanitary landfill in the municipality of Arbioto.

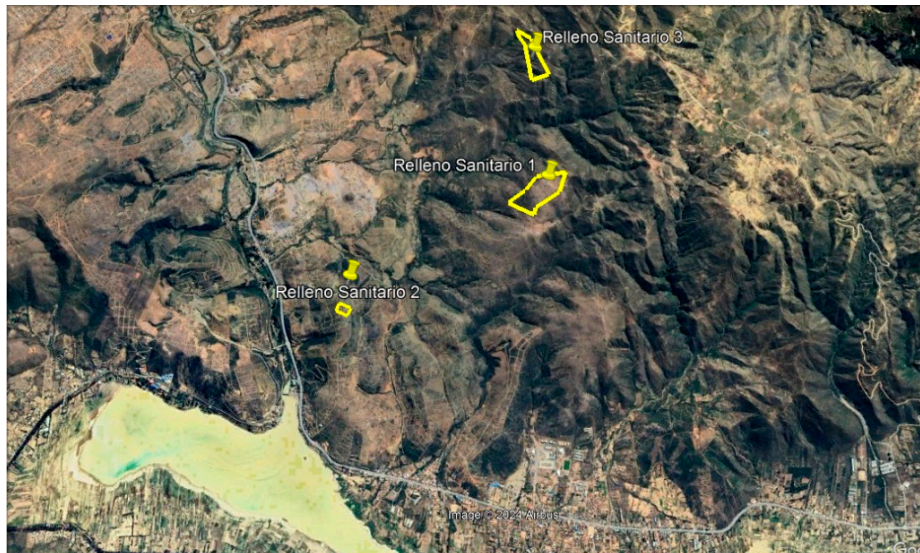


Figure 3. Satellite map of the final landfill site selection. Source: Author's elaboration.

3.3. Site Alternatives Identified

Three candidate sites were identified as suitable for sanitary landfill development:

Table 5. Landfill Site Alternatives Identified.

Site	Easting (m)	Northing (m)	Area (m ²)	Area (m ²)
Site 1	812367.00	8061779.00	149,795.25	14.98
Site 2	810050.00	8060550.00	13,274.12	1.33
Site 3	812364.00	8063307.00	132,105.58	13.21

Source: Author's elaboration.

All identified sites are located in District 5, within the communities of Olimpo and Tackoloma, in the Municipality of Arbieto.

3.5. Interpretation

The findings confirm that, despite the municipality's challenging topography and environmental constraints, there are viable sites for the establishment of a sanitary landfill. Specifically, Site 1, with an area of 14.98 ha, presents the most favorable conditions due to its sufficient distance from water bodies, urban areas, and its stable geological features.

The application of a Boolean logic multicriteria model ensures transparency, objectivity, and replicability, providing a robust decision-making tool for future waste management planning in Arbieto.

The Municipality of Arbieto covers a total area of 15,967.75 hectares. Based on the multicriteria spatial analysis, three potential sites were identified as optimal locations for a future sanitary landfill. Among them, Site 1 (14.98 ha) and Site 3 (13.21 ha) present the most favorable areas for future waste disposal infrastructure, while Site 2 (1.33 ha) offers a smaller but technically suitable alternative.

These results provide a technically grounded foundation for advancing towards the planning, design, and implementation of a sanitary landfill system, ensuring environmental protection, public health, and compliance with international standards.

4. Discussion

The selection of the optimal site for the final disposal of solid waste in the municipality of Arbiето was carried out by applying a multicriteria analysis model within a GIS environment, where each variable was reclassified into a binary format (value 1 if the criterion was met, value 0 if not). The criteria included slopes lower than 15°, distances greater than 500 meters from rivers, roads, and population centers, the presence of stable geological formations, and areas with minimal or no vegetation cover. Subsequently, a Boolean overlay technique was applied in ArcGIS by multiplying all the layers that simultaneously met the defined criteria. Thus, only the areas with a value of 1 across all layers were identified as potentially suitable zones for the construction of a sanitary landfill.

The results demonstrated that the optimal location for the future sanitary landfill is concentrated in the northern part of the municipality, specifically in District 5, within the communities of Olimpo and Tackoloma, at UTM coordinates 812367.00 m E, 8061779.00 m N. These findings confirm the working hypothesis that a multicriteria analysis methodology within a GIS environment would allow the identification of technically, environmentally, and socially appropriate areas for final waste disposal in rural contexts such as Arbiето.

When compared with international studies, the results are consistent with those reported by Bera et al. [2] in India, Ampofo et al. [3] in Ghana, and Barros et al. [1] in Brazil, where Boolean and multicriteria overlay models were also applied for landfill siting in rural or peri-urban territories. Similar to those studies, the use of GIS tools enabled the efficient management of multiple technical, environmental, and social criteria, contributing to a more objective and replicable planning process.

The identification of suitable areas in Arbiето highlights the importance of proactively planning the integrated management of solid waste by prioritizing the acquisition and protection of suitable land for sanitary landfills. Therefore, it is essential for the Autonomous Municipal Government of Arbiето to manage the legalization of the selected plots, prevent future illegal settlements, and guarantee their exclusive use for technical waste disposal. Additionally, it will be crucial to implement socialization processes with local communities to ensure social acceptance of the project and strengthen participatory governance.

Finally, for future research directions, it is recommended to incorporate dynamic scenario analyses of urban growth and population expansion, as well as to evaluate complementary alternatives such as transfer stations, waste valorization facilities, and waste generation minimization strategies. Furthermore, the model could be enhanced by integrating multicriteria weighting methods like the Analytic Hierarchy Process (AHP) for more complex scenarios or by including more detailed environmental impact simulations based on pollutant dispersion models.

5. Conclusions

The methodology applied through the use of ArcGIS software and the review of relevant literature enabled the selection of suitable sites for the final disposal of municipal solid waste in the municipality of Arbiето. By applying defined selection criteria, it was possible to identify specific areas that should be protected from illegal settlements to ensure proper integrated solid waste management.

Historically, the final disposal of waste in Arbiето has been conducted through open dumps, burning, or burial of waste across all districts, leading to serious social issues, environmental contamination, and public health risks. If no corrective measures are taken, these problems will intensify in the short term due to population growth and urban expansion.

The diagnostic process, based on GIS data and maps obtained from the PTDI of Arbiето and processed through ArcGIS, provided a clear identification of zones suitable for final waste disposal. The analysis of shapefiles related to topography, hydrography, road networks, population centers, geology, and vegetation cover allowed the pinpointing of the most appropriate locations for establishing a sanitary landfill.

Urban sprawl and informal settlements have placed increasing pressure on the local environment, causing significant land-use changes and generating further risks to public health. Soil contamination from improperly managed solid waste remains a critical issue in the municipality,

underscoring the urgent need for an integrated waste management system beginning with the selection of an appropriate final disposal site.

Moreover, community education and environmental awareness campaigns conducted alongside the technical work constitute a key contribution. In the short to medium term, these actions are expected to foster concrete environmental protection measures and promote sustainable practices among the local population.

6. Patents

No patents have resulted from the work reported in this manuscript.

Author Contributions: Conceptualization, E.T.A.; methodology, E.T.A.; software, E.T.A.; validation, E.T.A.; formal analysis, E.T.A.; investigation, E.T.A.; resources, E.T.A.; data curation, E.T.A.; writing—original draft preparation, E.T.A.; writing—review and editing, E.T.A.; visualization, E.T.A.; supervision, E.T.A.; project administration, E.T.A. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The spatial layers used in this study are publicly available from the Plan Territorial de Desarrollo Integral (PTDI) of Arbieta and the Instituto Geográfico Militar (IGM). The DEM data were obtained from the ASTGTM2 tiles S18W066 and S18W067.

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Conflicts of Interest: The author declares no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

MSW	Municipal Solid Waste
GIS	Geographic Information Systems
DEM	Digital Elevation Model
PTDI	Integral Comprehensive Territorial Development Plan
MCDM	Multicriteria Decision Making

Appendix A.

Appendix A.1. Procedure for Multicriteria Analysis in ArcGIS

The step-by-step procedure for performing the multicriteria analysis for sanitary landfill site selection in ArcGIS is presented below:

Table A1. Procedure for Multicriteria Analysis in ArcGIS.

Step	Procedure Description	Tool Used	ArcGIS Menu
1	Load the georeferenced map of Arbieta municipality	Add Data	Shapefile Distri_oficial
2	Load the Digital Elevation Model (DEM)	Add Data	DEM ASTGTM2_S18W066,

			DEM
			ASTGTM2_S18W067
3	Generate the slope map from DEM	Slope	ArcToolbox > Spatial Analyst Tools > Surface > Slope
4	Reclassify slope map (0–15% = 1; >15% = 0)	Reclassify	ArcToolbox > Spatial Analyst Tools > Reclassify
5	Load rivers shapefile	Add Data	Shapefile Rivers
6	Create Euclidean distance map from rivers	Euclidean Distance	ArcToolbox > Spatial Analyst Tools > Distance > Euclidean Distance
7	Reclassify distance to rivers (>500m = 1; ≤500m = 0)	Reclassify	ArcToolbox > Spatial Analyst Tools > Reclassify
8	Load road network shapefile	Add Data	Shapefile Local Roads
9	Create Euclidean distance map from roads	Euclidean Distance	ArcToolbox > Spatial Analyst Tools > Distance > Euclidean Distance
10	Reclassify distance to roads (>500m = 1; ≤500m = 0)	Reclassify	ArcToolbox > Spatial Analyst Tools > Reclassify
11	Load population centers shapefile	Add Data	Shapefile Localities
12	Create Euclidean distance map from population centers	Euclidean Distance	ArcToolbox > Spatial Analyst Tools > Distance > Euclidean Distance
13	Reclassify distance to population centers (>500m = 1; ≤500m = 0)	Reclassify	ArcToolbox > Spatial Analyst Tools > Reclassify
14	Load vegetation cover shapefile	Add Data	Shapefile Native Vegetation
15	Reclassify vegetation cover (no vegetation, grasslands, shrublands = 1; forests = 0)	Reclassify	ArcToolbox > Spatial Analyst Tools > Reclassify
16	Load geology shapefile	Add Data	Shapefile Geology
17	Reclassify geological formations (stable formations = 1; unstable formations = 0)	Reclassify	ArcToolbox > Spatial Analyst Tools > Reclassify
18	Perform raster overlay (logical intersection)	Raster Calculator	ArcToolbox > Spatial Analyst Tools > Map Algebra > Raster Calculator

19	Generate final suitability map	Raster Overlay	Result of logical AND operation
20	Export final map in raster and shapefile formats	Export Data	ArcGIS Output Options

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