A Combined GIS-AHP Approach for Sanitary Landfill Selection in Tangub City, Philippines

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Abstract

Solid waste management remains a major challenge in the Philippines, particularly due to the limited availability of sanitary landfills that meet environmental and regulatory standards. According to recent records, 210 local government units (LGUs) still lack access to sanitary landfill facilities. This study applies an integrated Geographic Information System (GIS) and Analytic Hierarchy Process (AHP) approach to identify suitable sanitary landfill sites in Tangub City, Southern Philippines. GIS-based spatial analysis excluded environmentally, and socially constrained areas based on proximity to built-up areas and water bodies, ecological sensitivity, elevation, slope, road accessibility, and minimum land area requirements. From the city's total land area of approximately 17,899.8 hectares, only 230 hectares (1.28%) were identified as suitable, yielding ten candidate sites. These sites were evaluated using AHP, with six criteria weighed based on expert judgment. Proximity to water bodies (0.38) and built-up areas (0.23) received the highest weights. The results indicate that San Vicente achieved the highest overall suitability score (0.234), followed by Capalaran (0.124) and Bintana (0.116). Consistency ratios for all pairwise comparisons were within acceptable limits (CR < 0.10), confirming the reliability of expert judgments. Sensitivity analysis further demonstrated that San Vicente remained the top-ranked site under most weighting scenarios, indicating strong robustness. The findings provide a data-driven and replicable framework to support sustainable landfill siting decisions for Tangub City and similar LGUs in the Philippines.

***Keywords**:* analytic hierarchy process, facility location, Geographic Information System, sensitivity analysis

1. Introduction

Solid waste management remains a growing global concern, affecting both developed and developing countries across urban and rural environments (Abdel-Shafy & Mansour, 2018). The challenge is compounded by rapid population growth, urbanization, economic development, and rural-to-urban migration, all of which contribute to the increasing volume of solid waste. In the absence of proper waste handling, uncontrolled disposal can severely impact environmental and public health by contaminating groundwater and surface water, degrading soil quality, and increasing air pollution (Chattopadhyay *et al.*, 2009). These environmental hazards may lead to serious health conditions, including diarrhea, typhoid, cholera, and hepatitis A (Buncag *et al.*, 2019).

To address these impacts, both governments and communities have implemented various waste management strategies. Among the most adopted approaches are the "3Rs" reduce, reuse, and recycle — which help to minimize waste generation but do not eliminate it entirely. Incineration is another method used to reduce waste volume; however, it poses environmental risks by releasing harmful gases that contribute to air pollution and climate change. In this context, sanitary landfills continue to play a vital role in integrated waste management systems, providing an engineered solution for final waste disposal that minimizes risks to human health and the environment (Chabuk *et al.*, 2016).

Despite global advancements in sanitary landfill development, the Philippines continues to face considerable challenges. Improper waste disposal persists, primarily due to inadequate landfill facilities and limited technical capacity among local government units (LGUs) (Coracero *et al.*, 2021). As of 2022, only 189 sanitary landfills are operational nationwide, leaving 210 LGUs, including Tangub City, without access to proper disposal infrastructure (Department of Environment and Natural Resources [DENR], 2022). While the DENR advocates landfill development under the Ecological Solid Waste Management Act of 2000, identifying suitable sites remains a critical obstacle. Many proposed locations are rejected due to poor site selection, as unsuitable areas can lead to leachate leakage, contaminating nearby water sources even when modern engineering standards are applied (Clapano, 2001; DENR, 2013).

Given these challenges, there is a pressing need for a more systematic, data-driven, and objective approach to landfill site selection, one that integrates both spatial and decision-making criteria. This study addresses that need by applying a combined Geographic Information System (GIS) and AHP) methodology to identify the most suitable site for a sanitary landfill in Tangub City, Philippines. The primary objective is to select a location that meets environmental, social, and economic considerations, while also ensuring community acceptability and long-term sustainability.

GIS is employed to exclude unsuitable areas based on spatial constraints such as elevation, proximity to water bodies and residential settlements, road accessibility, and ecological sensitivity. AHP is then applied to rank the remaining candidate sites by assigning weights to each criterion through expert pairwise comparisons. This structured multi-criteria decision-making process facilitates a comprehensive and transparent evaluation of site suitability.

The integration of GIS and AHP has demonstrated effectiveness in similar contexts worldwide, offering a replicable, evidence-based framework for addressing complex spatial planning problems. Comparable international applications of the GIS–AHP framework are integrated into this introduction to establish methodological context and identify gaps relevant to Philippine LGUs. Furthermore, a sensitivity analysis is conducted to evaluate the robustness of the selected site under different weighting scenarios.

Ultimately, this study aims to support Tangub City and other comparable LGUs in making informed, sustainable decisions regarding landfill siting. The findings are intended to contribute to the enhancement of solid waste management infrastructure in the Philippines through a scientifically grounded and policy-relevant framework

To situate the present study within the broader body of research, it is necessary to examine how previous studies have applied spatial and multi-criteria decision-making approaches to landfill site selection. The selection of suitable sites for sanitary landfills is a complex spatial decision-making problem that requires integrating multiple, often conflicting, environmental, social, and economic factors. To address this challenge, numerous studies have demonstrated the effectiveness of integrating GIS and the AHP for landfill site selection. This combined approach enables the spatial exclusion of environmentally or socially sensitive areas through GIS, followed by multi-criteria prioritization and ranking using AHP. The result is a data-driven and decision-supportive framework that has gained wide acceptance in the field of environmental planning.

In Sarein, Ardabil Province, Iran, Safavian *et al.* (2015) successfully applied the GIS-AHP approach to identify an optimal landfill site that met specific topographic and infrastructural requirements, such as proximity to road networks and a general slope of two percent. Similarly, Chabuk *et al.* (2016) employed GIS in Al Qasim Qadhaa, Iraq, to process extensive spatial data and isolate suitable landfill sites based on fifteen environmental and infrastructural criteria. These included groundwater depth, slope, land use, and proximity to urban centers and ecologically sensitive areas. AHP was then used to assign relative weights to each criterion through expert-based pairwise comparisons, ensuring a transparent and structured decision-making process.

In Johor Bahru, Malaysia, Mohammed *et al.* (2019) demonstrated the integration of AHP-derived weights into GIS via weighted overlay analysis to generate landfill suitability maps. The consistency of expert judgments was evaluated using Saaty's consistency ratio (CR), which must remain below 0.1 to ensure logical coherence in the comparisons (Saaty, 1988; Schmidt *et al.*, 2015). This validation step is essential, as AHP relies on expert judgments that can vary with decision-makers' knowledge and experience (Namoco *et al.*, 2022). Ensuring consistency strengthens the reliability of the results and enhances the credibility of the selected sites.

Although the GIS-AHP framework has been extensively applied internationally, its use in the Philippines, particularly among small and medium-sized local government units (LGUs), remains limited. Existing Philippine studies on solid waste management are often descriptive or policy-oriented, with minimal spatial analysis or empirical evaluation of landfill site selection methods. Furthermore, local GIS-based siting studies typically employ multi-criteria decision analysis (MCDA) methods, such as Weighted Linear Combination (WLC), in which all candidate sites are retained for evaluation regardless of their suitability. These sites are generally classified as highly suitable, moderately suitable, marginally suitable, or unsuitable, y*et al*l are included in the final analysis.

In contrast, this study introduces methodological improvement by excluding clearly unsuitable areas during the GIS-based spatial filtering stage, rather than carrying them forward into the decision analysis phase. Only candidate sites that meet baseline environmental and regulatory thresholds are retained for further evaluation. AHP is then applied exclusively to rank these viable options based on weighted criteria. This two-stage process enhances methodological efficiency by preventing the dilution of analysis with unsuitable areas and by focusing resources on evaluating legitimate alternatives in greater depth. Additionally, by moving away from the WLC approach and emphasizing the sequential use of spatial filtering followed by AHP-based ranking, the study offers a more targeted and objective decision-making framework.

To further improve the robustness of landfill siting decisions, this study incorporates sensitivity analysis within the GIS-AHP framework. As described by Erkut and Tarimcilar (1991), sensitivity analysis evaluates how changes in the weights assigned to decision criteria influence the final ranking of suitable sites. This technique increases confidence in the results by determining whether the optimal site remains consistent under different weighting scenarios, thereby reducing uncertainty and facilitating stakeholder agreement. However, this step is rarely applied in landfill siting research, particularly in local government contexts. Its inclusion directly addresses a gap in existing literature by enhancing the robustness and transparency of the decision-making process.

This research addresses two critical gaps. First, it presents a localized, spatially integrated landfill siting framework applicable to Philippine LGUs, such as Tangub City. Second, it introduces methodological enhancements over conventional GIS-MCDA applications, particularly in the exclusion of unsuitable areas and the overall structure of the decision-making process. By integrating GIS, AHP, and sensitivity analysis into a refined three-phase approach, the study provides a robust, transparent, and replicable model for evidence-based landfill site selection. It aligns with the objectives of the Ecological Solid Waste Management Act (Republic Act No. 9003) and provides practical support to LGUs in overcoming the technical and procedural barriers to identifying and evaluating landfill sites.

2. Methodology

2.1 Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a structured decision-making method developed by Saaty (1988) that facilitates the decomposition of complex problems into simpler, more manageable components. It employs a hierarchical structure to represent the problem, followed by pairwise comparisons to determine the relative importance of each element, ultimately generating a ranked set of alternatives based on calculated priority weights. AHP typically comprises three levels: the goal, which defines the overall objective; the criteria, which serve as the factors used to evaluate the alternatives; and the alternatives themselves, which represent the possible options under consideration.

According to Schmidt *et al*. (2015), the implementation of the Analytic Hierarchy Process (AHP) typically follows six systematic steps: defining the decision goal, evaluation criteria, and available alternatives (1); conducting pairwise comparisons to assess the relative importance of each criterion (2); calculating the normalized priority weights for the criteria (3); synthesizing the criteria weights with the alternative scores to derive overall priorities (4); evaluating the consistency of the pairwise judgments to ensure logical coherence (5); and performing sensitivity analysis (6).

2.2 Defining the Decision Goal, Evaluation Criteria, and Available Alternatives

2.2.1 Defining the Decision Goal

In this study, the Analytic Hierarchy Process (AHP) was employed to determine the most suitable location for a sanitary landfill in Tangub City. The primary objective was to prioritize potential sites through a comprehensive evaluation of multiple criteria grouped into social, environmental, and economic factors.

2.2.2 Establishing the Evaluation Criteria

The criteria employed in this study were based on the National Solid Waste Management Commission (NSWMC) Resolution No. 64, Series of 2013, which introduces modified guidelines for the identification and suitability assessment of sanitary landfill sites. The NSWMC, the national agency responsible for overseeing the implementation of solid waste management policies in the Philippines, issued this resolution to ensure alignment with Republic Act No. 9003, or the Ecological Solid Waste Management Act of 2000, and the Department of Environment and Natural Resources (DENR) Administrative Order No. 98-50. The resolution provides updated, standardized criteria to assist local government units (LGUs) in identifying appropriate landfill sites, with a strong emphasis on environmental integrity, public health protection, and compliance with legal and technical requirements. The applicable evaluation criteria for landfill siting in Tangub City are presented in Table 1.

Table 1. Criteria and descriptions for assessing the suitability of potential landfill sites in Tangub City

Factors	Criteria	Description
Social	Proximity to built-up areas	Distance from houses, buildings, schools, and other social infrastructures
Environmental	Proximity to water bodies	Distance from rivers, lakes, and other water sources
	Proximity to local ecological condition	Distance from environmentally sensitive areas, including forest zones and the Mt. Malindang Range Natural Par
Economic	Area capacity	Total available land area
	Proximity to road network	Accessibility to existing roads
	Elevation	Altitude of the site

2.2.3 Identifying Alternatives/Suitable Landfill Sites using GIS

The identification of spatially suitable areas for sanitary landfill development in Tangub City was carried out using Quantum Geographic Information System (QGIS) version 3.22.3 (QGIS Development Team, 2021). This phase involved a structured geospatial analysis incorporating exclusionary social, environmental, and economic factors in accordance with national policy directives and the provisions of the city’s Comprehensive Land Use Plan (CLUP). The methodology was implemented in four sequential stages: data acquisition (1); constraint mapping and buffer application (2); spatial overlay and exclusion of unsuitable areas (3); and area threshold analysis to delineate viable landfill site candidates (4).

2.2.3.1 Data Acquisition

Relevant spatial datasets were obtained from national government agencies and open-access geospatial platforms to support the spatial analyses conducted in this study. The administrative base map of Tangub City was derived from the Philippines Common Operational Dataset for Administrative Boundaries (COD-AB), downloaded from the Humanitarian Data Exchange (HDX), which is based on official administrative boundary data from the National Mapping and Resource Information Authority (NAMRIA) (OCHA, 2022). Cartographic datasets, including built-up areas, water bodies, ecological zones, and road networks, were derived from OpenStreetMap data distributed through Geofabrik (OpenStreetMap Contributors, 2022; Geofabrik GmbH, 2022). The administrative boundaries of the urban barangays were derived from the Tangub City Comprehensive Land Use Plan (Tangub City Government, 2022). In addition, a Digital Elevation Model (DEM) was obtained from the NASA Shuttle Radar Topography Mission (SRTM) Global 1 Arc Second Version 3 dataset through the NASA Earthdata platform and was used to derive elevation, slope, and flood risk maps. To ensure spatial consistency and analytical accuracy during the geoprocessing stages, all datasets were transformed into a common coordinate reference system appropriate for the geographic extent of Tangub City.

2.2.3.2 Constraint Mapping and Buffer Application

In accordance with the criteria set forth in National Solid Waste Management Commission (NSWMC) Resolution No. 64, Series of 2013, eight exclusionary constraints were identified to delineate areas unsuitable for sanitary landfill development. These constraints reflect considerations related to environmental sensitivity, proximity to human settlements, and exposure to natural hazards.

Each constraint was assigned a corresponding buffer zone based on regulatory setback distances, as summarized in Table 2.

Buffer zones were generated using the buffer function in QGIS and applied to the respective vector layers. Each constraint layer was then systematically prepared for spatial overlay analysis to facilitate the identification of unsuitable areas.

Table 2. Exclusionary constraints and buffer distances

Constraints	Buffer Distance
Religious institutions, educational facilities, and cemeteries	1,000 meters
Other built-up areas	250 meters
Water bodies (e.g., rivers, lakes, streams)	300 meters
Ecologically sensitive areas	500 meters
Major roads and highways	300 meters
Urban barangays	No buffer
Flood-prone areas	No buffer
Elevation above 300 meters	No buffer
Slopes exceeding 20%	No buffer

2.2.3.3 Spatial Overlay and Exclusion of Unsuitable Areas

Following the establishment of buffer zones, all constraint layers were overlaid onto the base map of Tangub City. Utilizing the difference vector processing function in QGIS, areas deemed unsuitable, including the defined buffer zones, were subtracted from the total land area. This spatial operation yielded a refined set of polygons representing preliminary suitable sites for landfill development, effectively excluding areas with environmental sensitivities, regulatory restrictions, and proximity to urban developments. Figures 1–6 present the spatial distribution of the constraint layers and the resulting exclusion zones.

Figure 1 illustrates the built-up areas in Tangub City (Figure 1a) and their corresponding buffer zones of 250 meters and 1,000 meters around critical facilities such as churches, schools, and cemeteries (Figure 1b). These areas are excluded from landfill development to minimize health and social impacts.

Figure 2 shows the water bodies within the city, including rivers and streams (Figure 2a), along with the 300-meter buffer zones applied to protect surface water from contamination risks (Figure 2b).

Figure 3 presents the locally identified ecological areas that require protection, such as forests or conservation zones (Figure 3a), and the 500-meter buffer zones established around them (Figure 3b), in accordance with environmental protection guidelines.

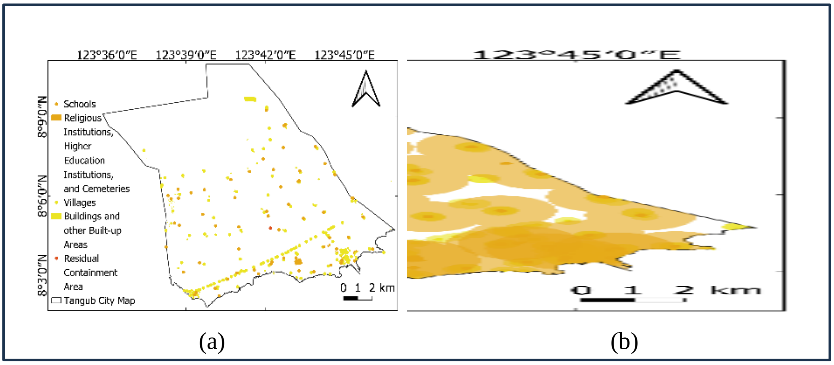

Figure 1. Built-up areas in Tangub City (a) and buffered built-up areas (b)

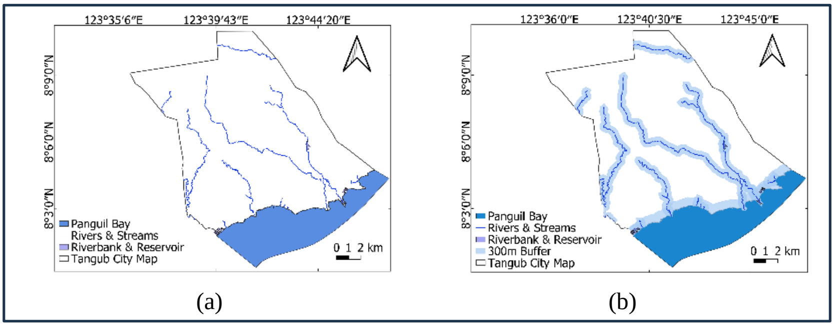

Figure 2. Water bodies (a) and buffered water bodies (b)

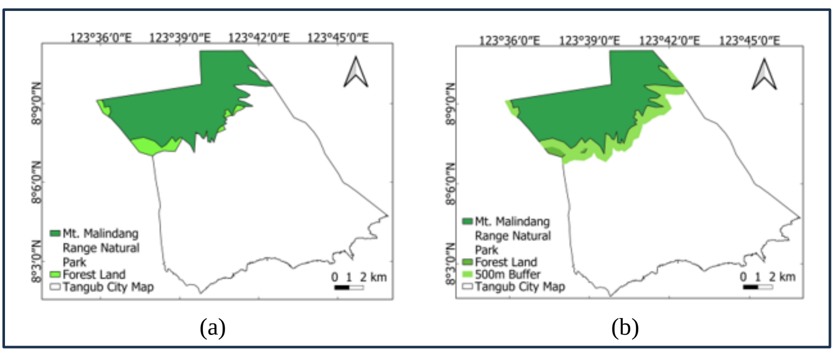

Figure 3. Local ecological condition (a) and buffered local ecological condition (b)

Figure 4 maps the major road networks across Tangub City (Figure 4a) and the applied 300-meter buffers (Figure 4b), which are intended to reduce exposure of landfills to transportation corridors while maintaining accessibility.

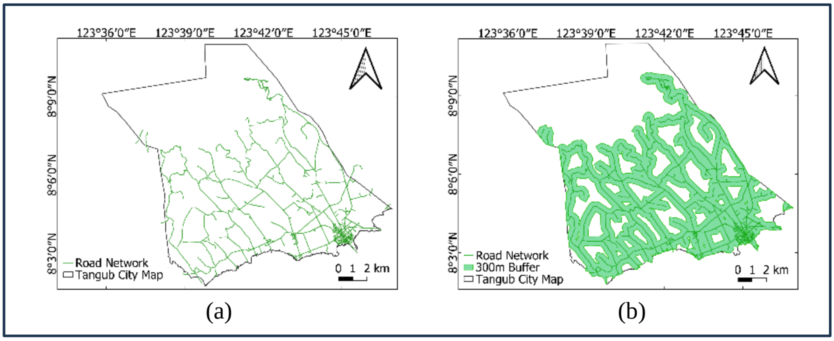

Figure 4. Road networks (a) and buffered road networks (b)

Figure 5 depicts the spatial distribution of urban barangays (Figure 5a), which are excluded from consideration due to their population density, and the flood-prone areas (Figure 5b) derived from elevation and hydrological data, where landfill construction is deemed unsuitable.

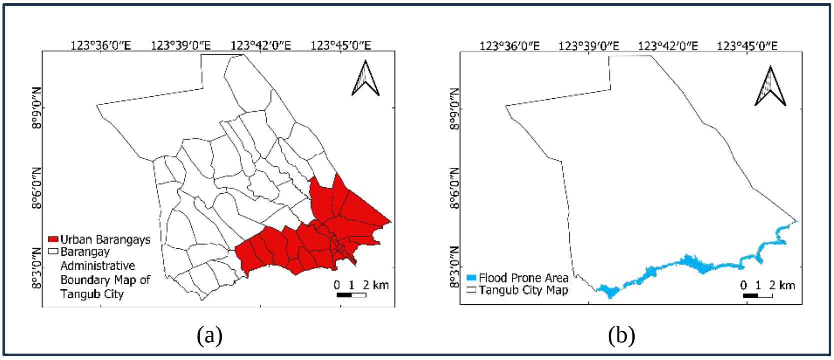

Figure 5. Urban centers (a) and flood-prone areas in Tangub City (b)

Figure 6 presents the elevation map of Tangub City (Figure 6a), which identifies areas exceeding the 300-meter threshold, as transporting solid waste to higher elevations typically entails greater fuel consumption and longer hauling times, thereby increasing operational costs. Additionally, the slope map (Figure 6b) highlights areas with gradients greater than 20%, which are considered unsuitable for landfill development due to challenges related to stability and construction feasibility.

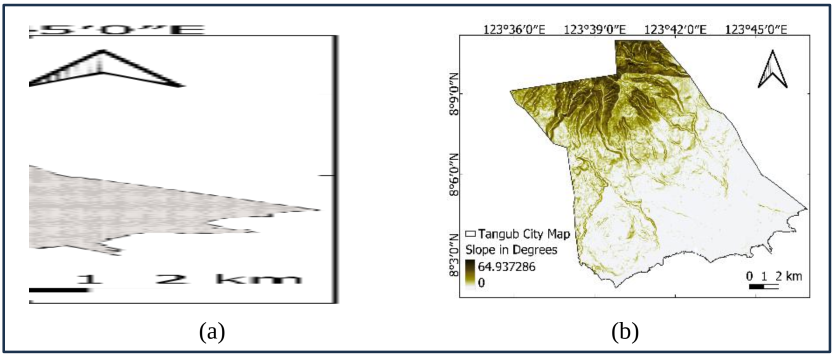

Figure 6. Elevation map (a) and slope map of Tangub City (b)

2.2.3.4 Minimum Area Thresholding

To ensure the long-term operational viability of a sanitary landfill, only contiguous land parcels that satisfied the minimum area requirement were retained for further analysis. According to National Solid Waste Management Commission (NSWMC) Resolution No. 64, Series of 2013, a landfill intended to serve a population of 100,000 requires a minimum area of 2.6 hectares. Applying this guideline proportionally to Tangub City's projected population and estimated waste generation, a minimum site area of 2.38 hectares was established. All candidate sites falling below this threshold were excluded from subsequent spatial analysis and decision-making processes.

The geospatial workflow for the identification of suitable landfill sites is illustrated in Figure 7.

Figure 7 presents the workflow diagram summarizing the step-by-step implementation of GIS in the landfill site selection process. This includes constraint mapping and buffer application, spatial overlay analysis, and the elimination of unsuitable areas prior to AHP-based ranking.

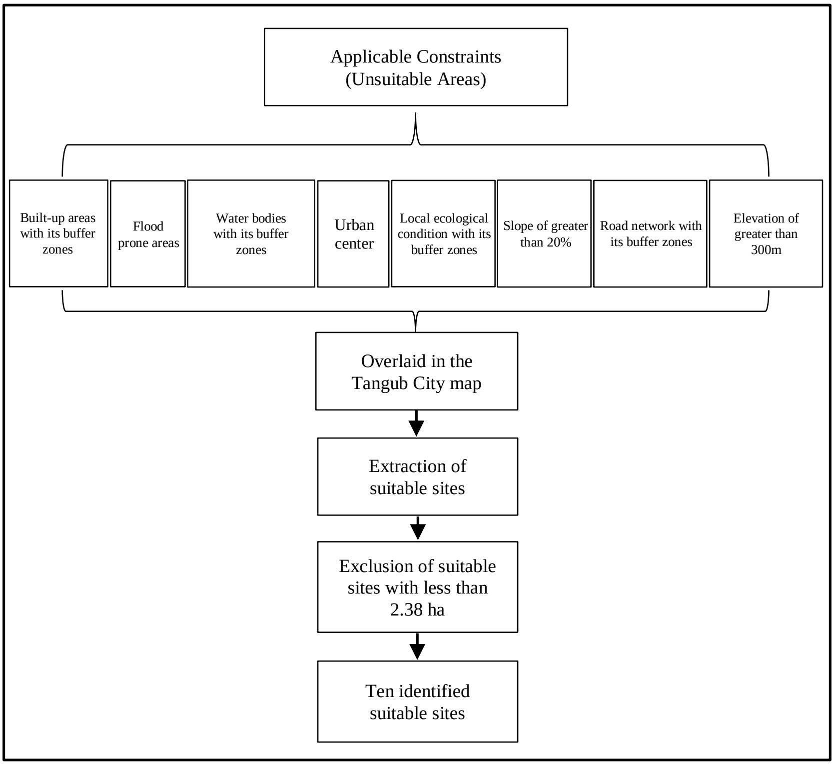

Figure 7. Flow chart of the implementation of GIS in identifying suitable sites for sanitary landfill

2.3 Performing Pairwise Comparison for the Criteria

Pairwise comparison is a fundamental step in the Analytic Hierarchy Process (AHP) that enables decision-makers to systematically evaluate the relative importance of each criterion or alternative. Rather than assessing all factors simultaneously, which can be cognitively demanding and prone to bias, pairwise comparison simplifies the process by focusing on two criteria at a time. This structured approach reduces cognitive overload, enhances the accuracy of expert judgments, and promotes internal consistency by allowing for the verification of logical coherence in responses.

Accurate determination of criteria weights is critical in landfill site selection, as it directly influences the prioritization of suitable sites. Criteria such as elevation, area capacity, proximity to built-up areas, water bodies, local ecological condition, and road network vary in significance according to the specific local context. Inappropriately assigning weights to these criteria can result in site selections that are socially unacceptable, environmentally unsound, or economically unfeasible. Consequently, the pairwise comparison method not only facilitates transparent and defensible decision-making but also ensures that landfill siting decisions embody a balanced integration of environmental, social, and economic considerations.

Subjective preferences are quantified using Saaty's 1 to 9 fundamental scale (Table 3), which converts qualitative judgments (for example, "Criterion A is moderately more important than Criterion B") into numerical values. These values form the basis for constructing the pairwise comparison matrix, from which normalized weights are derived.

The prioritization of criteria was conducted by a panel of experts comprising the head of the City Planning and Development Office, the Supervising Environmental Management Specialist from the City Environment and Natural Resources Office, the Gukom (tribal leader) of the Subanen Indigenous Cultural Community in Tangub City, and three licensed environmental planners from the academic sector. Each expert independently provided a judgment on the relative importance of the evaluation criteria.

Table 3. Saaty's 1-9 points scale for pairwise comparison matrix

Intensity of Importance	Definition
1	The two criteria are of equal importance in sanitary landfill site selection
2	One criterion is between equally to moderately important over another
3	One criterion is moderately important over another
4	One criterion is between moderately to strongly important over another
5	One criterion is strongly important over another
6	One criterion is between strongly to very strongly important over another
7	One criterion is very strongly favored over another, and its dominance is demonstrated in practice
8	One criterion is between very to extremely important over another
9	The importance of one criterion over another is affirmed in the highest possible order

Based on these expert assessments, individual pairwise comparison matrices were constructed. For each matrix, when one criterion was deemed more important than another, the corresponding Saaty score was assigned to the relevant cell in the matrix. The reciprocal value was then entered into the opposing cell across the diagonal, ensuring consistency according to the fundamental AHP principle of reciprocity. This process was governed by Equation 1:

$$c_{ji} = \frac{1}{c_{ij}} \tag{1}$$

where c_{ij} is the importance of criterion i over criterion j, and c_{ji} represents the inverse.

This process continues until all the values in the row i and column j were identified. The values of c_{ij} ($i = 1,2,3 \ldots n$ and $j = 1,2,3 \ldots n$) were used to represent the importance of a criterion in sanitary landfill site selection (Hussain, 2004; Uyan, 2013), and the complete comparison matrix for deriving the weight for each criterion can be represented in the decision matrix given in Equation 2.

$$DM_{criteria} = \begin{bmatrix} \text{Criterion} & 1 & 2 & 3 & \cdots & n \\ 1 & c_{11} & c_{12} & c_{13} & \cdots & c_{1n} \\ 2 & c_{21} & c_{22} & c_{23} & \cdots & c_{2n} \\ 3 & c_{31} & c_{32} & c_{33} & \cdots & c_{3n} \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ n & c_{n1} & c_{n2} & c_{n3} & \cdots & c_{nn} \\ \text{Sum} & \sum_{i=1}^{n} c_{i1} & \sum_{i=1}^{n} c_{i2} & \sum_{i=1}^{n} c_{i3} & \cdots & \sum_{i=1}^{n} c_{in} \end{bmatrix} \tag{2}$$

2.4 Calculating Normalized Priority Weights for the Criteria

In AHP, priority weights represent the relative importance of criteria in achieving the overall goal of the decision-making process. These weights indicate how much influence each criterion has on landfill siting relative to the others, with all weights summing to 1 for comparability.

The first step in deriving these weights is to compute the geometric mean of the ratings for each criterion, as provided by the expert committee and presented in the decision matrix $DM_{criteria}$. Calculating the geometric mean is essential because it provides a consistent, mathematically appropriate method for deriving priority weights from individual pairwise comparison matrices, ensuring that expert judgments are accurately transformed into reliable, proportional weights.

For this study, the expert committee comprised six members ($k = 6$) who evaluated the priority criteria. The geometric mean of their evaluations was computed to obtain the consolidated weight of each criterion, with the resulting values presented in the matrix shown in Equation 3.

$$GM_{criteria} = \begin{bmatrix} \text{Criterion} & 1 & 2 & \cdots & n \\ 1 & G_{11} & G_{12} & \cdots & G_{1n} \\ 2 & G_{21} & G_{22} & \cdots & G_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ n & G_{n1} & G_{n2} & \cdots & G_{nn} \\ \text{Sum} & \sum_{i=1}^{n} G_{i1} & \sum_{i=1}^{n} G_{i2} & \cdots & \sum_{i=1}^{n} G_{in} \end{bmatrix} \tag{3}$$

where

$$G_{ij} = \sqrt[k]{\prod_{s=1}^{k} c_{ij,s}}$$

Next, the consolidated values were transformed into a normalized matrix, an essential step for expressing the relative importance of each criterion on a common scale, with the sum of all weights equal to 1. This was achieved by dividing each value in a column of the matrix $GM_{criteria}$ by the sum of its corresponding column. Normalization ensures that the resulting priority weights are directly comparable and proportionally consistent across all criteria. The result of the normalized matrix is presented in Equation 4.

To determine the priority criteria and their corresponding weights, the average of the values in each row of the normalized matrix $NM_{criteria}$ was computed, with the results presented in the matrix shown in Equation 5.

$$NM_{criteria} = \begin{bmatrix} \text{Criterion} & 1 & 2 & \cdots & n \\ 1 & \frac{G_{11}}{\sum_{i=1}^{n} G_{i1}} & \frac{G_{12}}{\sum_{i=1}^{n} G_{i2}} & \cdots & \frac{G_{1n}}{\sum_{i=1}^{n} G_{in}} \\ 2 & \frac{G_{21}}{\sum_{i=1}^{n} G_{i1}} & \frac{G_{22}}{\sum_{i=1}^{n} G_{i2}} & \cdots & \frac{G_{2n}}{\sum_{i=1}^{n} G_{in}} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ n & \frac{G_{n1}}{\sum_{i=1}^{n} G_{i1}} & \frac{G_{n2}}{\sum_{i=1}^{n} G_{i2}} & \cdots & \frac{G_{nn}}{\sum_{i=1}^{n} G_{in}} \\ \text{Sum} & 1 & 1 & \cdots & 1 \end{bmatrix} \tag{4}$$

$$W_{criteria} = \begin{bmatrix} \text{Criterion} & \text{Priority Criterion} \\ 1 & \frac{\frac{G_{11}}{\sum_{i=1}^{n} G_{i1}} + \frac{G_{12}}{\sum_{i=1}^{n} G_{i2}} + \cdots + \frac{G_{1n}}{\sum_{i=1}^{n} G_{in}}}{n} \\ 2 & \frac{\frac{G_{21}}{\sum_{i=1}^{n} G_{i1}} + \frac{G_{22}}{\sum_{i=1}^{n} G_{i2}} + \cdots + \frac{G_{2n}}{\sum_{i=1}^{n} G_{in}}}{n} \\ \vdots & \vdots \\ n & \frac{\frac{G_{n1}}{\sum_{i=1}^{n} G_{i1}} + \frac{G_{n2}}{\sum_{i=1}^{n} G_{i2}} + \cdots + \frac{G_{nn}}{\sum_{i=1}^{n} G_{in}}}{n} \end{bmatrix} \tag{5}$$

2.5 Ranking the Alternatives/Suitable Landfill Sites

The degree of suitability between two sites was determined by differences in their proximity to built-up areas, water bodies, local ecological condition, area capacity, the road network, and elevation. Larger differences corresponded to higher Saaty scores for the more favorable site, providing a quantitative basis for scoring that differs from the expert judgment used in determining criterion weights. Site measurements were obtained using QGIS functions and are presented in Table 4.

The range between the site with the highest measurement and the lowest measurement in proximity to built-up areas, water bodies, local ecological condition, area capacity, proximity to road network, and elevation of the sites' area was calculated using Equation 6.

$$R = |\, Vmax - Vmin \,| \tag{6}$$

where $Vmax$ is the maximum value and $Vmin$ is the minimum value.

Table 4. The area capacity, elevation and distance of the sites to built-up areas, water bodies, local ecological condition, and road network

Sites	Built-up Areas (M)	Water Bodies (M)	Local Ecological Condition (M)	Area Capacity (ha)	Road Network (m)	Elevation (m)
Bintana	578	1088	5719	34.8	329	151
Caniangan	734	477	4123	12.8	329	234
Capalaran	749	695	6697	28.9	300	129
Catagan - Taguite	327	394	3308	38.3	321	300
Guinabot - Silangit	286	773	4701	52.1	331	245
Prenza	470	451	7356	9.2	300	53
San Vicente	818	1494	6409	3.9	300	234
Silangit	462	653	5336	6.8	300	205
Silangit - San Vicente	366	1178	5251	39.4	300	234
Villaba	814	768	3467	3.5	329	277

After determining the range, it was divided by nine to create nine intervals. These nine-class intervals were the basis for assigning Saaty's score to one site over another. The larger the class interval to which the difference in measurement belongs, the better the suitability of the favorable site compared to another. The class intervals are presented in Table 5.

Using the established class interval, a pairwise comparison matrix was constructed for the sites under each criterion. The ranking of alternatives applied the same pairwise comparison and normalization procedure outlined in Section 2.4 but was performed separately for each criterion.

The landfill suitability ranking was then determined by multiplying the weight of the site by the weight of the criterion, as shown in Equation 7:

$$t = \sum_{i=1}^{n} WS_{t,i} * WC_i \quad t = 1, 2, \dots, n \tag{7}$$

where $WS_{t,i}$ is the weight of the site t in criterion i and WC_i is the weight of criterion i.

Table 5. Interval basis for the pairwise comparison of the sites

Intensity	Built-up Areas (M)	Water Bodies (M)	Local Ecological Condition (M)	Area Capacity (Ha)	Road Network (m)	Elevation (m)
1	0.00 – 59.11	0.00 – 122.22	0.00 – 449.78	0.00 – 5.40	0.00 – 3.44	0.00 – 27.44
2	59.12 – 118.22	122.23 – 244.44	449.79 – 899.56	5.41 – 10.80	3.45 – 6.89	27.45 – 54.89
3	118.23 – 177.33	244.45 – 366.67	899.57 – 1349.33	10.81 – 16.20	6.90 – 10.33	54.90 – 82.33
4	177.34 – 236.44	366.68 – 488.89	1349.34 – 1799.11	16.21 – 21.60	10.34 – 13.78	82.34 – 109.78
5	236.45 – 295.56	488.90 – 611.11	1799.12 – 2248.89	21.61 – 27.00	13.79 – 17.22	109.79 – 137.22
6	295.57 – 354.67	611.12 – 733.33	2248.90 – 2698.67	27.01 – 32.40	17.23 – 20.67	137.23 – 164.67
7	354.68 – 413.78	733.34 – 855.56	2698.68 – 3148.44	32.41 – 37.80	20.68 – 24.11	164.68 – 192.11
8	413.79 – 472.89	855.57 – 977.78	3148.45 – 3598.22	37.81 – 43.20	24.12 – 27.56	192.12 – 219.56
9	472.90 – 532.00	977.79– 1100.00	3598.23 – 4048.00	43.21 – 48.60	27.57 – 31.00	219.57 – 247.00

A schematic representation of the AHP implementation process—from goal definition through criteria weighting and alternative evaluation to final site ranking—is shown in Figure 8.

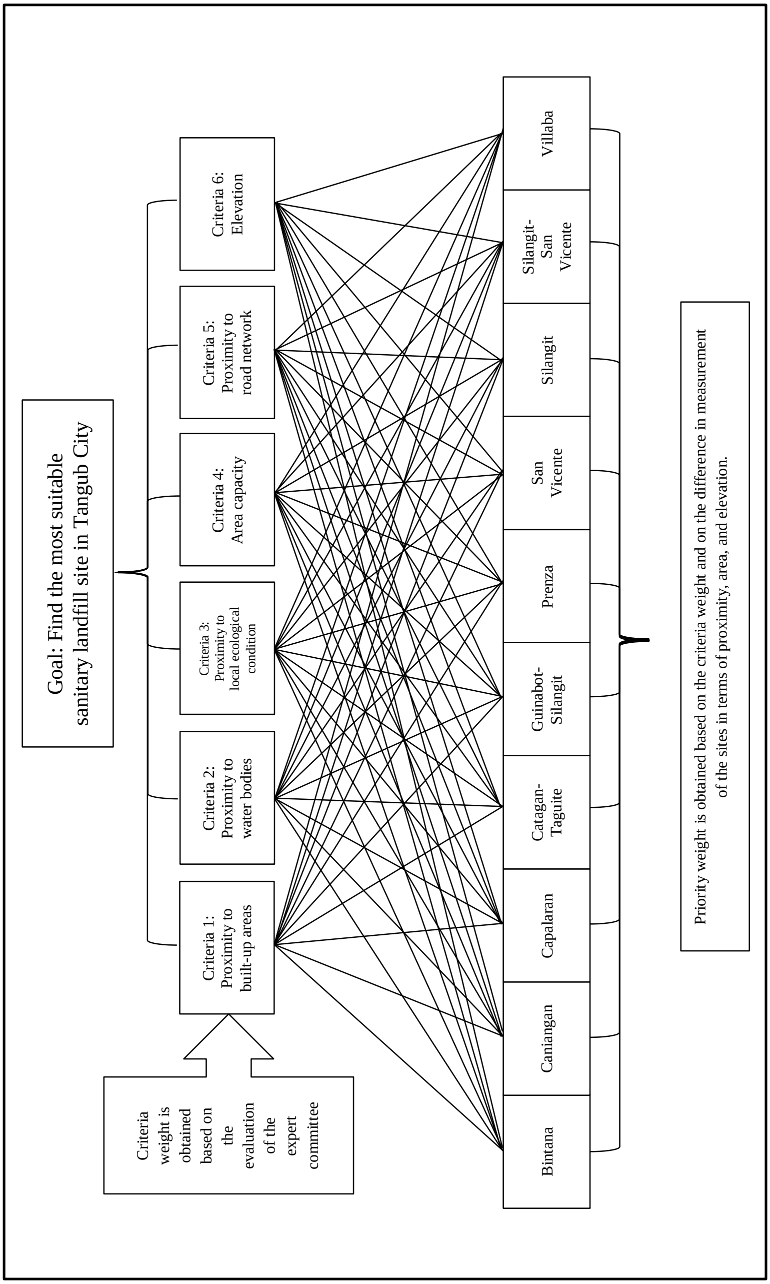

Figure 8. Flow chart of AHP implementation for identifying the most suitable sites for sanitary landfills

2.6 Consistency Evaluation

Given the subjective nature of pairwise comparisons, it is critical to assess the logical consistency of the judgments provided. This was achieved by computing the Consistency Ratio (CR) (Equation 8):

$$CR = CI/RI \tag{8}$$

Where:

- *CI* is the Consistency Index, derived from the principal eigenvalue of the matrix
- *RI* is the Random Index, a constant based on matrix size

A *CR* value of less than 0.10 indicates acceptable consistency (Saaty, 1988; Schmidt *et al*., 2015). If $CR \geq 0.10$, the matrix must be revised.

2.7 Sensitivity Analysis

To test the robustness of the landfill suitability rankings, a sensitivity analysis was conducted using Super Decisions software. The analysis employed a numerical incremental approach, in which the weight of one criterion was systematically varied while the weights of the others were held constant. The impact of these variations on the global ranking of alternatives was observed. This procedure ensured that the final decision was not unduly influenced by minor changes in criterion weights, thus reinforcing the credibility of the results (Leonelli, 2012; Librantz, 2016).

3. Results and Discussion

Tangub City, a fourth-class component city in Misamis Occidental, Philippines, encompasses approximately 17,899.8 hectares distributed across 55 barangays. Spatial analysis using GIS identified 230 hectares (approximately 1.28% of the total land area) as suitable for sanitary landfill development (Figure 9). Ten candidate sites were identified: Bintana, Caniangan, Capalaran, Catagan-Taguite, Guinabot-Silangit, Prenza, San Vicente, Silangit, Silangit-San Vicente, and Villaba.

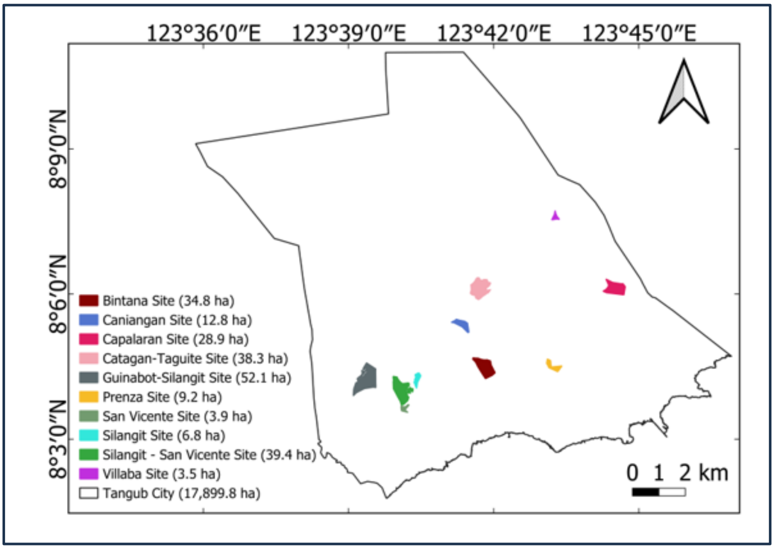

Figure 9. Identified suitable landfill sites in Tangub City with their area capacity in hectares

Among the six landfill siting criteria applicable in Tangub City (Table 6), proximity to water bodies received the highest priority due to the critical need to protect water resources, followed by proximity to built-up areas and Ecological Condition. Economic factors, including area capacity, road network proximity, and elevation, were assigned relatively lower weights to reflect their lesser influence on overall site suitability.

Table 6. Criteria weights for sanitary landfill siting in Tangub City

Criteria	Weights
Proximity to built-up areas	0.23
Proximity to water bodies	0.38
Proximity to local ecological condition	0.22
Area capacity	0.07
Proximity to road network	0.05
Elevation of the sites’ area	0.05

Applying these criteria weights, overall suitability scores were calculated for each candidate site (Table 7). The San Vicente site attained the highest suitability score (0.234), primarily due to its considerable distance from both water bodies and built-up areas, which were the most heavily weighted criteria. Capalaran ranked second, demonstrating consistently high suitability across multiple criteria. The subsequent rankings were Bintana, Prenza, Silangit-San Vicente, Villaba, Guinabot-Silangit, Silangit, Caniangan, and Catagan-Taguite.

Table 7. Overall priority weight of the suitable sites

Site Name	Weight	Ranking
Bintana	0.116	3rd
Caniangan	0.058	9th
Capalaran	0.124	2nd
Catagan-Taguite	0.032	10th
Guinabot-Silangit	0.065	7th
Prenza	0.113	4th
San Vicente	0.234	1st
Silangit	0.061	8th
Silangit-San Vicente	0.112	5th
Villaba	0.085	6th

The consistency ratios for pairwise comparisons of criteria and alternative sites (Tables 8 and 9) were within acceptable thresholds, indicating reliable expert judgment.

Table 8. Degree of consistency for the pairwise comparison of criteria

Consistency Measure	Value
Consistency Index	0.035
Consistency Ratio	0.028

Table 9. Degree of consistency for the pairwise comparison of suitable sites in different criteria

Criteria	Consistency Index	Consistency Ratio
Built-up areas	0.031	0.021
Water bodies	0.030	0.020
Local ecological condition	0.039	0.026
Area capacity	0.028	0.018
Road network	0.017	0.011
Elevation	0.025	0.016

Sensitivity analyses were conducted to assess the robustness of site rankings under variations in criteria weights. Varying the weight assigned to proximity to water bodies from its baseline value of 0.38 to values ranging from 0.05 to 1.0 consistently maintained San Vicente’s position as the most suitable site (Figure 10a). Similarly, varying the weight of proximity to built-up areas from its baseline value of 0.23 to values ranging from 0.12 to 1.0 preserved San Vicente’s ranking as the highest-priority site (Figure 10b). Variations in the weight assigned to proximity to local ecological condition revealed a threshold effect, wherein San Vicente maintained the highest ranking up to a criterion weight of 0.30, beyond which Prenza became the highest-priority site (Figure 11a). Increasing the weight of area capacity above 0.35 resulted in Guinabot-Silangit attaining the highest priority due to its larger available land area (Figure 11b). Changes in the weight assigned to proximity to road networks, ranging from 0 to 0.78, consistently maintained San Vicente as the highest-priority site (Figure 12a). However, when the weight assigned to elevation exceeded 0.30, a shift in priority ranking occurred, with Prenza becoming the most suitable site (Figure 12b).

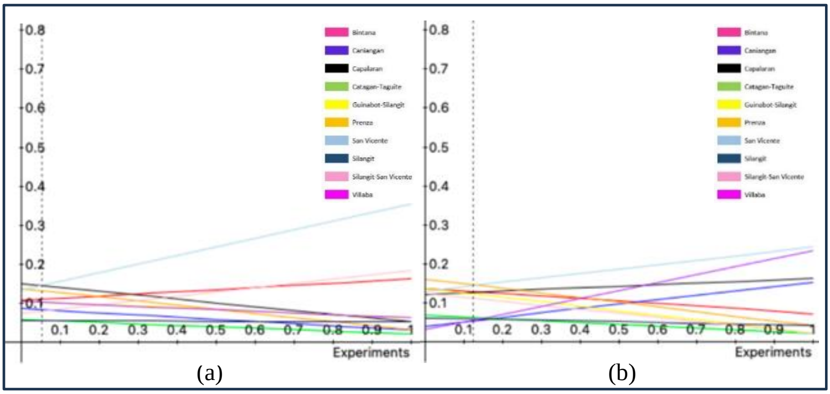

Figure 10. AHP sensitivity on the changes of criteria weight of proximity to water bodies (a) and built-up areas (b)

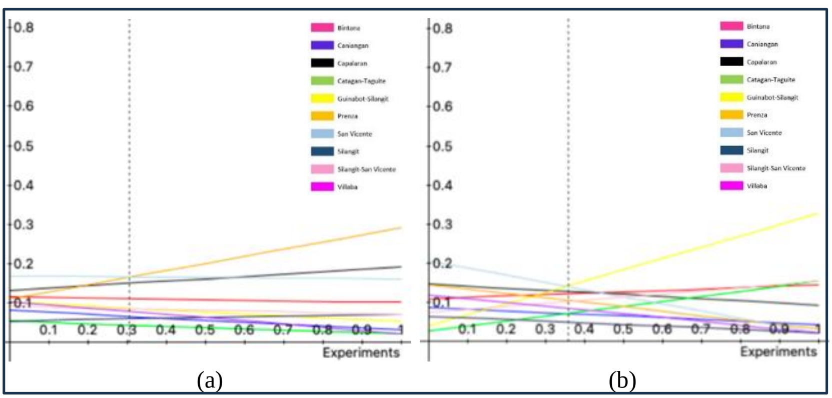

Figure 11. AHP sensitivity on the changes of criteria weight of proximity to local ecological condition (a) and area capacity (b)

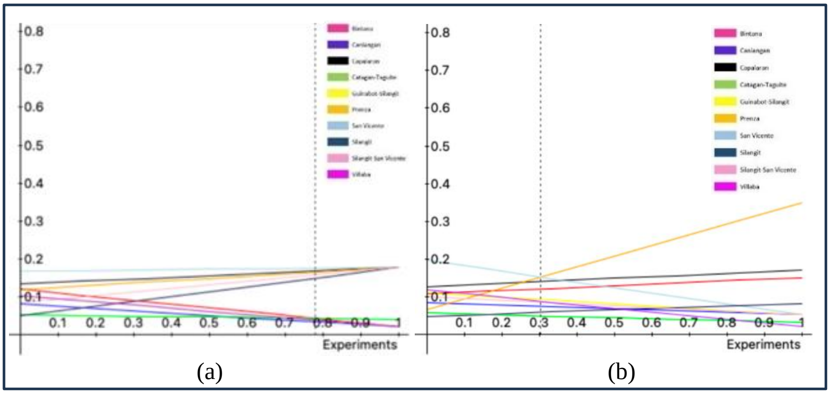

Figure 12. AHP sensitivity to the changes in the criteria weight of proximity to the road network (a) and the weight of elevation of the site's area (b)

Overall, San Vicente's ranking demonstrated stability within ±0.05 variations in criteria weights, whereas the relative rankings of the second through fifth sites were sensitive to such changes, suggesting potential shifts contingent on stakeholder priorities.

The identification of only 1.28% of Tangub City's land area as suitable for sanitary landfill development underscores the stringent constraints imposed by environmental, social, and regulatory factors. These constraints align with the Philippine government's rigorous siting guidelines designed to safeguard human health and environmental integrity.

The prioritization of proximity to water bodies reflects the city's reliance on Panguil Bay, a critical marine ecosystem and a source of livelihood. Protecting this water body from landfill-related pollution is essential to maintain ecological services and public health. The elevated weighting for proximity to built-up areas acknowledges the adverse impacts of landfill operations, including air quality degradation and noise pollution, on nearby populations, justifying the need to minimize exposure risks.

Assigning significant weight to local ecological condition demonstrates recognition of Tangub City's unique biodiversity, particularly its adjacency to Mt. Malindang Range Natural Park. This prioritization integrates conservation objectives within waste management planning, ensuring that landfill development does not compromise protected areas and endangered species habitats.

Economic factors, though critical in practical implementation, were assigned lower weights to emphasize environmental and social considerations over cost efficiency. This reflects the complex trade-offs local governments face, in which the availability and accessibility of land often conflict with ecological and public health priorities.

The application of AHP in this study facilitated a structured and transparent multi-criteria decision-making process. However, the method's inherent subjectivity rooted in expert judgment warrants careful consideration. Although consistency ratios indicated coherent comparisons, potential biases and the limited scope of stakeholder involvement could influence the weighting outcomes.

Moreover, GIS-based spatial analysis relies on the precision and resolution of available data, which may omit dynamic land use changes and sociopolitical factors such as community acceptance, which are difficult to quantify but critical to landfill siting success.

The sensitivity analyses confirm the robustness of the San Vicente site selection across a range of weighting scenarios, enhancing confidence in its prioritization. Nevertheless, the sensitivity observed among suitable sites highlights the need for flexible, adaptive management approaches that can accommodate shifting priorities and emerging constraints.

Future research should aim to incorporate participatory decision-making frameworks involving diverse stakeholder groups and integrate temporal dynamics and socioeconomic trends to further refine landfill site suitability assessments in Tangub City.

4. Conclusion and Recommendation

This study identified 10 potential sites for sanitary landfill development in Tangub City using GIS and AHP. The identified sites, Bintana, Caniangan, Capalaran, Catagan-Taguite, Guinabot-Silangit, Prenza, San Vicente, Silangit, Silangit-San Vicente, and Villaba, collectively account for only 1.28 percent of the city's total land area. This limited availability underscores the spatial constraints faced by local government units (LGUs) in complying with national landfill siting guidelines. As urban expansion and land use changes continue, the availability of suitable areas for sanitary landfill development is expected to decline further.

The site selection process followed a structured multi-criteria approach. Six key criteria were considered in the evaluation: proximity to water bodies, proximity to built-up areas, proximity to local ecological condition, area capacity, proximity to the road network, and elevation. These criteria were prioritized through expert judgment, with proximity to water bodies receiving the highest weight due to its critical implications for environmental protection, public health, and local economic activities. This was followed by proximity to built-up areas and proximity to ecologically sensitive zones such as the Mt. Malindang Range Natural Park.

The prioritization of these criteria is based on their potential to minimize adverse impacts from landfill development. For instance, siting landfills far from water bodies reduces the risk of leachate contamination and protects aquatic ecosystems such as Panguil Bay, a vital source of seafood and livelihood for local communities. Similarly, greater distances from built up areas reduce the exposure of residents to landfill related nuisances such as odor, noise, and traffic.

The combined GIS-AHP methodology enabled a systematic and spatially informed evaluation of all candidate sites by integrating geospatial data with stakeholder preferences. The GIS component provided spatial analysis capabilities to identify technically feasible areas, while the AHP component supported quantitative comparison among alternatives based on expert assigned weights. This ensured that all relevant factors were simultaneously evaluated, thereby enhancing the transparency and rigor of the decision-making process.

To further assess the robustness of the results, a sensitivity analysis was conducted to examine how variations in the weights of individual criteria affected the ranking of candidate sites. The analysis revealed that San Vicente consistently maintained the highest suitability ranking across a wide range of weighting scenarios. This site is located at a substantial distance from both water bodies at 1,494 meters and built-up areas at 818 meters, aligning with the two most heavily weighted criteria. Additionally, it meets acceptable thresholds for the remaining criteria, making it the most resilient and justifiable choice for sanitary landfill development.

Given these findings, several recommendations are proposed. The San Vicente site may be considered a priority candidate for further feasibility assessment and detailed environmental evaluation, as it demonstrated the highest suitability and stability across all evaluation and sensitivity analysis scenarios. Local government units are encouraged to adopt GIS-AHP as a decision-support approach in environmental and infrastructure planning to ensure that spatial decisions are data-driven and responsive to multiple criteria. Considering the continuous reduction of suitable land areas due to urban expansion and changing land-use patterns, local governments should proactively identify and preserve additional potential landfill sites using updated geospatial datasets. Furthermore, the criteria weights applied in landfill suitability assessments should be periodically reviewed and adjusted to incorporate emerging considerations, including climate resilience, disaster risk reduction, and changes in waste generation patterns. Future landfill site selection studies should also integrate public consultation and social acceptability assessments to complement technical and environmental evaluations, thereby strengthening the long-term feasibility and acceptance of landfill development projects.

In conclusion, this study provides a replicable and evidence-based approach to landfill siting under complex regulatory and environmental constraints. The integrated use of GIS and AHP with sensitivity analysis not only streamlines the decision-making process but also ensures that site selection is aligned with sustainable development goals and national solid waste management policies.

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