Land Suitability Mapping and Analysis for Sanitary Landfill Site in Batangas City, Philippines

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Abstract—The Philippines generates 18 million tons of waste annually, with a projected increase of 13.44% due to rapid urbanization and population growth. This growing waste volume poses significant challenges for Local Government Units (LGUs) in establishing sanitary landfills capable of handling the load. LGUs conduct land suitability studies to identify optimal sites for existing and new sanitary landfill (SLF) facilities to ensure compliance with proximity to protected and settlement areas. Each LGU faces unique challenges due to varying physical characteristics, economic and environmental conditions, local policies, and adherence to national laws and regulations. Geographic Information System (GIS) applications are widely used to aid LGUs in expediting the SLF site selection process. However, GIS requires geospatial data, which some LGUs struggle to provide due to limited data availability and capacity. The local government of Batangas City faces similar challenges, as its current socioeconomic and environmental conditions threaten the suitability of its existing sanitary landfill. Consequently, a new landfill site is anticipated. Three thematic maps based on three factors of land suitability for the city's landfill sites were created. The suitability of the existing landfill facility is compromised by the growing number of nearby settlements. Several barangays with highly viable areas were identified. However,further environmental impact assessments and community acceptability surveys are recommended to avoid potential nuisances or hazards to public health and safety. This study encourages the city to develop policies for managing current landfill sites near residential areas and other infrastructures due to the scarcity of suitable lands for SLF facilities.

Keywords—*Sanitary landfill, site suitability, Municipal Solid Waste (MSW).*

I. INTRODUCTION

Annually, around 2.01 billion tons of municipal solid waste (MSW) are generated globally, with 33% being disposed of improperly, and only 20% are being recycled and composted [4]. In 2018, the Philippines was the third-largest yearly generator of solid waste in Southeast Asian countries[11]. As the country addresses the environmental impacts of urbanization and the needs of its growing population, waste management has also been a critical issue. The Philippine National Solid Waste Management Commission (NSWMC) projected a 13.44% increase in solid waste from 14.66 million tons in 2015. The Philippines generates approximately 49,452 tons of household solid waste daily, resulting in over 18 million tons annually, surpassing the anticipated 2015 increase [7]. The Department of Natural and Environmental Resources (DENR) emphasizes the need for sanitary landfills in all towns and municipalities, according to the quantity of waste generated. The DENR stresses that unless the capacity of waste that ends up in sanitary landfills is reduced and the number of solid waste management treatment facilities is increased, the remaining 60 percent of the MSW will be improperly disposed of, contaminating the environment. Effective waste management requires careful consideration of various parameters including proximity to urban areas, water bodies, and other environmentally protected areas, to prevent pollution, minimize environmental damage, and lessen stigma for residents living near the facility[12]. This is especially critical for disposing of non-recyclable home, and other residual wastes.

It is imperative that all Philippine local government units (LGUs) closely adhere to Republic Act 9003, also known as the Ecological Solid Waste Management Act of 2000 [11].The RA 9003, mandates that every Local Government Unit (LGU) in the country to plan and execute the management and monitoring of solid waste disposal and landfill areas [8]. Efforts are being made to establish sanitary landfills capable of handling these substantial waste volumes and to identify optimal sites for these facilities. However, the rapid growth of urban populations and the expansion of city built-up areas make it difficult for urbanized cities to locate suitable places for SLF. Each LGU faces unique challenges due to differing physical characteristics, economic and environmental conditions, and local policies. Furthermore, choosing a landfill location is a complex process and

an important issue in urban planning, requiring the assessment and evaluation of various influential factors, such as physical, environmental, social, or economic considerations[10].

Compliance with applicable Philippine laws and regulations is required during the selection process, including health and sanitation regulations, environmental restrictions, geospatial analysis, site evaluation, cultural and protected site proximity, and other social and economic factors [2].Many land-use allocation and site selection studies utilize spatial analysis to generate maps that are used to create policies and make choices about land use [3].However, selecting suitable lands for SLF sites requires the assurance of a rational decision-making process to minimize environmental impacts while avoiding potential public opposition. This necessitates the use of Geographical Information System (GIS) applications and the consideration of both attributes and spatial data [5].Integrating a multi-criteria decision-making (MCDM) tool into the GIS tool enhances the analysis over traditional approaches in the planning phase of site selection studies [1].

For LGUs with limited data availability and capacity, it is essential to prioritize critical factors when identifying potential landfill sites. Batangas City, a coastal city in the Southeastern part of Batangas Province in the Philippines, faces challenges in managing the anticipated increase in waste due to its rapidly growing population and changes in lifestyle. The city's built-up areas are expanding, occupying much of its total land area of approximately 28,541.44 hectares, with a population of 329,874 and a predicted household size of 67,910 according to a Philippine Statistics Authority survey in 2021. Batangas City currently relies on one LGU-owned operational SLF site, the Batangas City Sanitary Landfill (BCSLF), located in Barangay San Jose Sico, more than 14 kilometers from the city center[7]. The city's expanding urban center and the presence of livestock farms and settlement areas near the landfill present additional challenges.

In the next five years, Batangas City anticipates expanding its landfill to handle the waste generated by its growing population. This study aimed to evaluate the suitability of the existing Batangas Sanitary Landfill site. Simulating the effects of the current socioeconomic and environmental conditions on the Batangas sanitary disposal facility helps determine the appropriateness of the existing landfill site. This analysis identifies whether suitable locations are still available within the city. If the current site is deemed unsuitable, the study locates potential new landfill sites to be considered for the local planning phase.

II. MATERIALS AND METHODS

A systematic technique applying Geographic Information System (GIS) technologies was used to examine the appropriateness of the current SLF site in Batangas City. The procedure began by comprehending the research area's characteristics, assessing and weighing appropriate suitability criteria, listing all essential data, and implementing the GIS.

A. Area of the Study

This study focuses on Batangas City mainland only (see Map below), located in the CALABARZON region of the Philippines.The primary objective is to assess the suitability of the current Batangas Sanitary Landfill and identify potential new locations for future SLFfacilities within the city. Batangas City, a first-class coastal component city, is situated in the southernmost part of Batangas Province, facing Batangas Bay at coordinates 13° 45′ N, 121° 03′ E, and approximately 13.80 meters (45.10 feet) above sea level.The Calumpang River runs through the city from northwest to southwest, and the area includes several protected marine and terrestrial environments. Batangas City encompasses 282.96 square kilometers (109.25 square miles), accounting for 9.08 percent of the total land area of Batangas Province. The city is divided into 105 barangays, of which only 30 have adopted a zero-waste approach, leading to 90 percent of household waste being sent to landfills[13].According to the 2020 Philippine Statistics Authority (PSA) survey data, Batangas City is one of the fastest-urbanizing cities in the Philippines. It has a population of 351,437 and a density of 1,200 people per square kilometer, with 87,196 households.

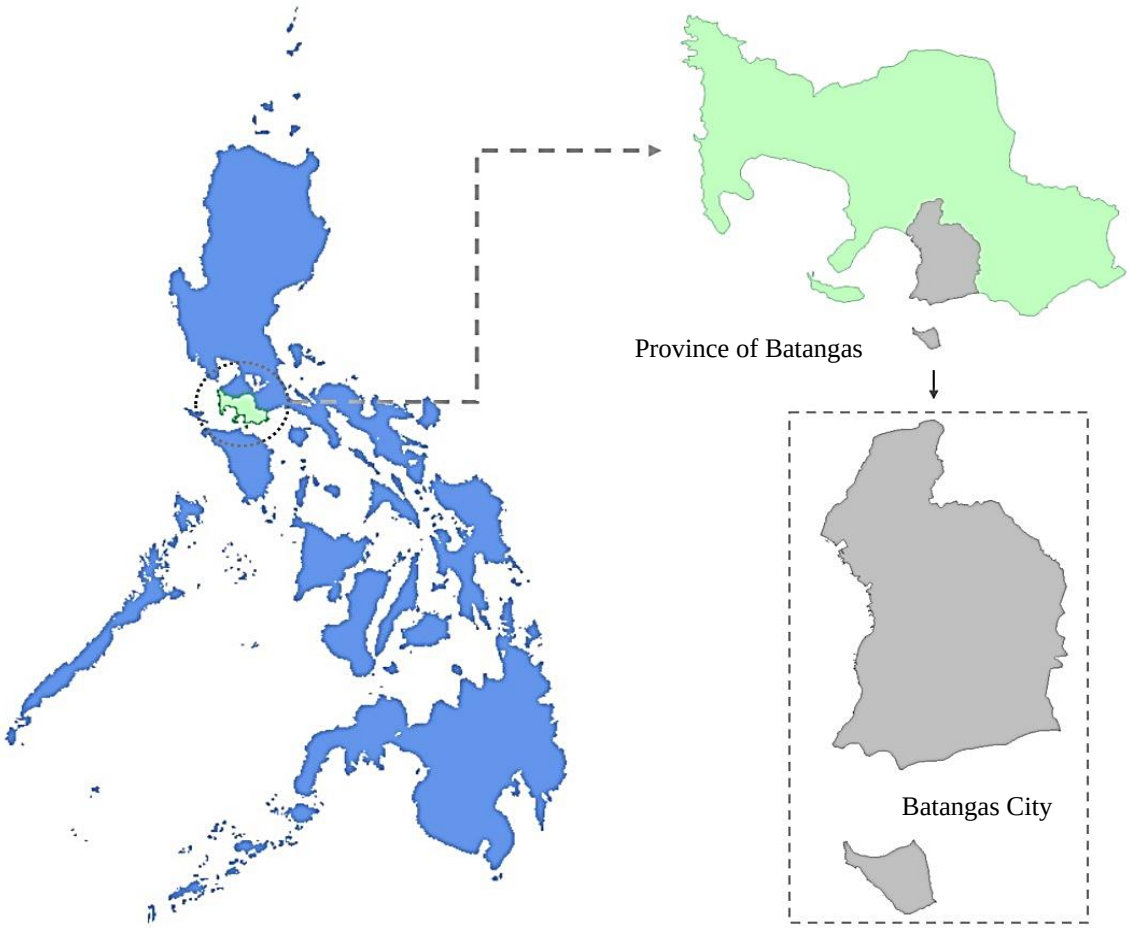

Fig 1: Location of Study Area

B. Conceptual Framework

The researcher develops a conceptual framework while considering the site selection criteria provided for in the RA 9003 Ecological Solid Waste Management Act of 2000 and its implementing rules, regulations, and guidelines from the Climate and Disaster Risk Reduction Assessment (CDRA) process.Previous studies established that environmental is the most commonly prioritized criterion for landfill siting criteria, followed by economic and social criteria. Among the sub-criteria, distance to surface waters is the most frequently preferred [6]. This study took into account Batangas City's particular issues in establishing whether the existing disposal site is still acceptable and recommending prospective new landfill locations. Three primary the land suitability aspects were considered: social, economic, and environmental. The necessary distance from settlement areas, cultural amenities, highways, rivers, surface waterways, forest cover, protected areas, and percentage slope indicates site suitability for landfill facilities.

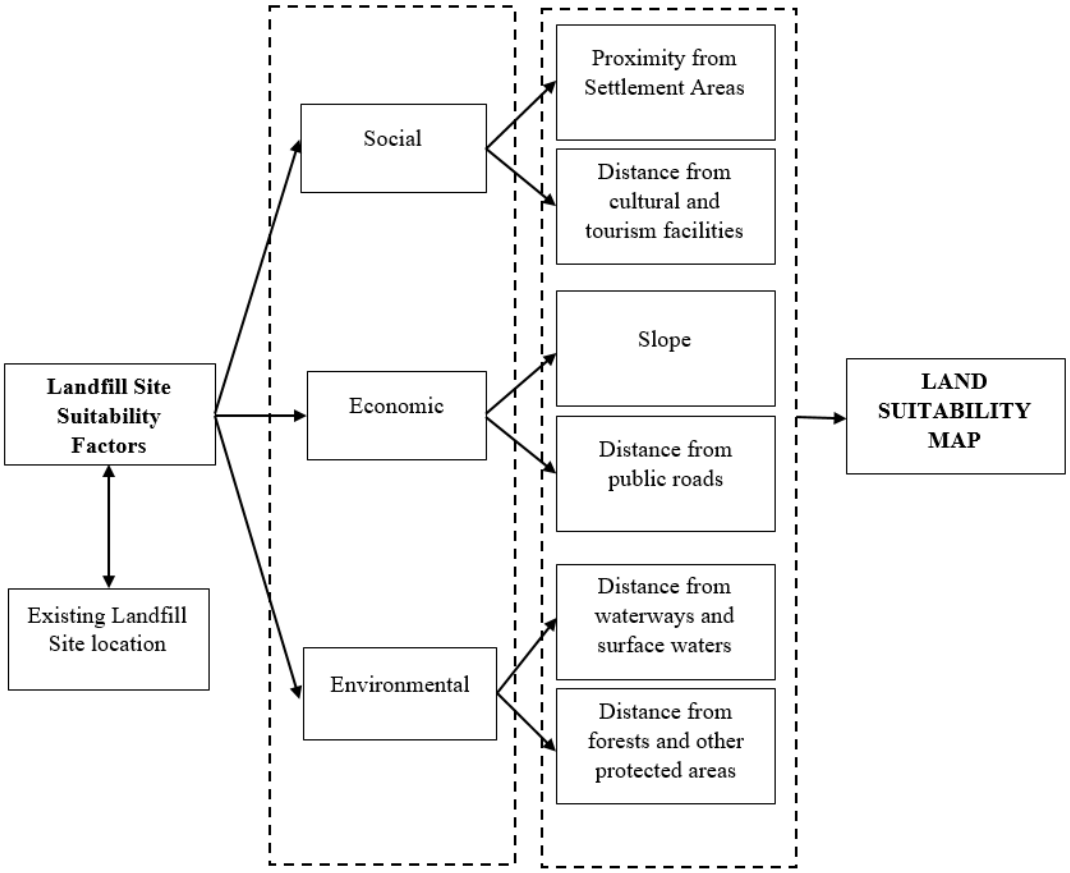

Fig 2: Conceptual framework diagram

C. SLF Site Selection Criteria

Detailed datasets relating to the proximity of the landfill site to residential areas, water bodies, and sensitive ecosystems were obtained to capture critical environmental considerations. Using proximity from various sub-criteria of the city's physical features were considered (See Table 1). The political boundary map of Batangas City was used as the base map.

TABLE 1. SLF SITE SUITABILITY CRITERIA

Item	**Main Criteria**	**Sub-criteria**	**Proximity & Suitability Requirements**	
1	Economic	Distance from roads	Suitability is from 0-200 meters distance from Roads or otherwise	
		Slope	0-10 percent 10-20 percent 20-30 percent 30% -above	Very high suitability Moderate Low Not suitable
2	Environmental	Distance from rivers and other water bodies	Suitability is from 0 - 1 kilometer distance from water bodies or otherwise	
		Land cover and protected areas	Strict protection use Multiple-use Production agricultural and agri-industrial zone General use	Not suitable Moderate Low Very high suitability
3	Social	Distance from settlement areas	Suitability is from 0-1 kilometer from settlement areas or otherwise	
		Distance from cultural &tourism facilities	Suitability is from 0-1 kilometer from cultural or tourism facilities or otherwise	

Note: Site selection criteria were based from the minimum requirements of Ecological Solid Waste Management Act of 2000 (RA 9003) implementing rules and regulations.

D. Secondary Data Collection Method

Relevant spatial data of two different types – shapefiles and map images, encompassing land use, soil type, topography, and hydrological features, was requested from City Planning and Development Office (CPDO) of Batangas City and were utilized in this study for spatial overlay analysis. Other spatial data were downloaded from online open resources such as the National Mapping and Resource Information Authority of the Philippines (NAMRIA), Google Earth, and GIS MAP Info.

E. Analytical Hierarchy Process

Analytical Hierarchy Process or AHP, integrated within the ArcGIS environment, was employed to quantify the relative importance of each criterion and determine their respective influences on landfill suitability. The AHP process and Weighted Linear Combination (WLC) are the most widely used Multi-Criteria Decision-Making (MCDM) methods for weighting the criteria and ranking the alternatives, respectively [9].This step facilitated a systematic and objective decision-making process. A pairwise procedure was also used to rank the physical landfill suitability characteristics (See Table 2).

TABLE 2. WEIGHT ASSIGNMENTS FOR LANDFILL SUITABILITY FACTORS

Item	**Main Criteria**	**Sub-criteria**	**Score**	**% Weight**	**Rank**	**Score**	**Rank**	**Overall % weight**
1	Base Map	Barangay political boundary	7	2.98	6	60	2	28.50
2	Economic	Distance from roads	29	28.00	4			
		Slope	31	12.55	3			
3	Environmental	Distance from rivers and other water bodies	47	19.03	1	94	1	40.00
		Land cover and protected areas	47	19.03	1			
4	Social	Distance from settlement areas	47	19.03	2	73	3	31.50
		Distance from cultural & tourism facilities	27	10.93	5			
		Total	**235**	**38.06**	**-**	**235**	**-**	**100**

Score: (T.L.Saaty, 1987) 1 - Equal importance, 3 - Moderate importance of one over other, 5 - Essential or strong importance, 7 - Very strong importance, 9 - Extreme importance

To objectively assess the significance of each criterion, weights were assigned based on expert opinion and relevant literature. This step ensured a balanced consideration of factors influencing landfill suitability. Six (6) pairwise comparisons were considered to test the weights' consistency per the main criteria. The consistency ratio was computed using an online AHP priorities calculator. The resulting priorities are shown in Table 3. The resulting weights were based on the principal eigenvector of the decision matrix with a principal eigenvalue of 5.391, Eigenvector solution of 6 interactions, and delta equal to 2.7E-9.

TABLE 3. PAIRWISE COMPARISON RESULTING WEIGHT ASSIGNMENTS

Category		**Priority**	**Rank**	**(+)**	**(-)**
1	Protected Areas	46%	1	24.7%	24.7%
2	Cultural	13.2%	4	5.7%	5.7%
3	Built Areas	13.5%	3	4.9%	4.9%
5	River/ Water bodies	23.8%	2	12.8%	12.8%
5	Road	3.5%	5	0.9%	0.9%

Note: Number of comparisons = 10; Consistency ratio (CR) = 8.7%

F. GIS Process

This study uses a licensed ArcGIS 10.8.1 version to simulate the landfill suitability of the existing facility and determine potential areas for new landfill facilities in Batangas City, Philippines. The GIS process begins with data preparation, followed by data analysis, and finally, suitability modeling.

1) ***Data Preparation:***Maps and other geographic data needed for suitability analyses (see Table 4) were categorized according to file format. All maps were clipped and transformed from raster images to shapefiles, or vice versa, using ArcGIS tools transform techniques to ensure compatibility. All secondary image data, such as land use maps, topographic maps, and road networks, were digitalized. The downloaded large-extent maps, such asrivers and other surface water bodies, were trimmed and outlined with a polygon clip focused only on Batangas City's political boundaries. Images from Google Maps were also transformed and digitalized to at least 50 meters (1mm x 50,000).

TABLE 4. SANITARY LANDFILL (SLF) SUITABILITY MAPPING DATA REQUIREMENTS

Item	Criteria	Data Requirement
1	Barangay political boundary	City boundary map*
2	Distance from roads	Google Earth extracted road network map
3	Slope	Topographic*or slope map
4	Distance from rivers and other water bodies	Google Earth extracted river and surface water maps [14], [15]
5	Land cover and protected areas	Land use or Land cover map*
6	Distance from settlement areas	Land use and built-up map*
s7	Distance from cultural & tourism facilities	Built-up map* and Google Earth extracted location map

*Data source: Batangas City Planning and Development Office

2) ***Data Analysis:***This studyinitially conducted spatial analyses based on the proximity criterion for landfill site selectionto produce the data requirements for suitability analysis. The spatial data analysis was grouped based on the three main criteria: economic, environmental, and physical features. Using map overlaying techniques and buffer creation per proximity requirements, thematic maps for site selection were created asa basis for subsequent criteria weight-based suitability analyses. The Barangay political boundary or administrative map was used as the base map, given the topographic data, which also depicted the landform details, drainage, road networks, and other man-made features of the city. Aslope profile map was first created by running the ArcGIS slope command under the spatial analysis toolbox. Analysis of land terrain suitability was coded based on slope percentage (see Table 1). Proximity analysis of thematic maps such as road networks, rivers, waterways, land cover, protected areas, settlement areas, and cultural and tourism facilities maps were processed by applying the output buffer (ArcGIS toolbox > Spatial Analysis > Geoprocessing > Buffer) of required easement from lines and areas of the geographical features. Then, a reclassification tool was applied to classify zones such as unsuitable, moderate, low, or very high suitability (ArcGIS toolbox > Spatial Analysis > Reclass > Reclassify).

3) ***Suitability Modelling:***Thematic maps of identified proximity criteria were prepared after the establishment of the modeling objectives and SLF suitability criteria for analysis. The spatial data process (ArcGIS toolbox > Spatial Analysis > Overlay > Weighted Overlay) and two levels of analysis were performedby economic, environmental, and physical features. Three thematic maps were produced at the first level of suitability analysis of each factor. Finally, a land suitability map was produced using raster-based overlay analysis for new SLF suitable areas.

III. RESULTS AND DISCUSSION

Maps created using GIS spatial analysis techniques were able to identify ideal areas for new SLF based on proximity and suitability criteria. Suitability maps for each criterion were generated and it illustrates parts of Batangas City that led to recommendations for prospective viable SLF sites.

A. Suitability of existing Batangas City SLF site

The current SLF site in Batangas City was reevaluated using six (6) suitability physical factors: economic, environmental, and physical. The SLF site, located in Barangay Jose Sico near the Barangay Bilogo townhall at (latitude 13° 44' 52") north and (121° 9' 58") east, is presently accessible by road. The SFL location is anticipated to be roughly 440 meters from poultry and animal farms, with few other dwellings close(See Table 5).The current SLF site is no longer appropriate due to the 1-kilometer buffer distance required from the road and population zones though it demonstrates suitability when taking into account the site's slope, as well as moderate suitability for distance from protected areas and cultural facilities.

TABLE 5. EXISTING BATANGAS LANDFILL SITE SUITABILITY

Main Criteria	**Appearance (in Time New Roman or Times)**	
	Sub-criteria	**Suitability**
Economic	Distance from roads	Not suitable
	Slope	Very high suitability
Environmental	Distance from rivers and other water bodies	Not suitable
	Land cover and protected areas	Moderate
Social	Distance from settlement areas	Not suitable
	Distance from cultural & tourism facilities	Suitable
Overall		Not suitable

B. SLF site suitability of Batangas City land areas

Maps were made using ArcGIS technology to determine the suitability of Batangas City's land covering for additional dump sites. In Figure 1, the left image shows a thematic map locating suitable landfill areas based on the required 1-kilometer distance from the road and slope, and the right image depicts a map of suitable sites for new SLF, taking into account environmental factors such as distance from rivers, land cover, and protected areas. The Socialfactor land suitability map (Figure 4) illustrates suitable sites based on distance from settlements and cultural and tourism facilities. These prospective locations, taking into consideration three distinct factors, may be considered while also considering the design parameters for the new SLF, such as its projected capacity, quantities and nature of wastes, range, and diversity of wastes to be processed at the facility as suggested in the technical guidebook on solid waste disposal design, operation, and management in the Philippines.

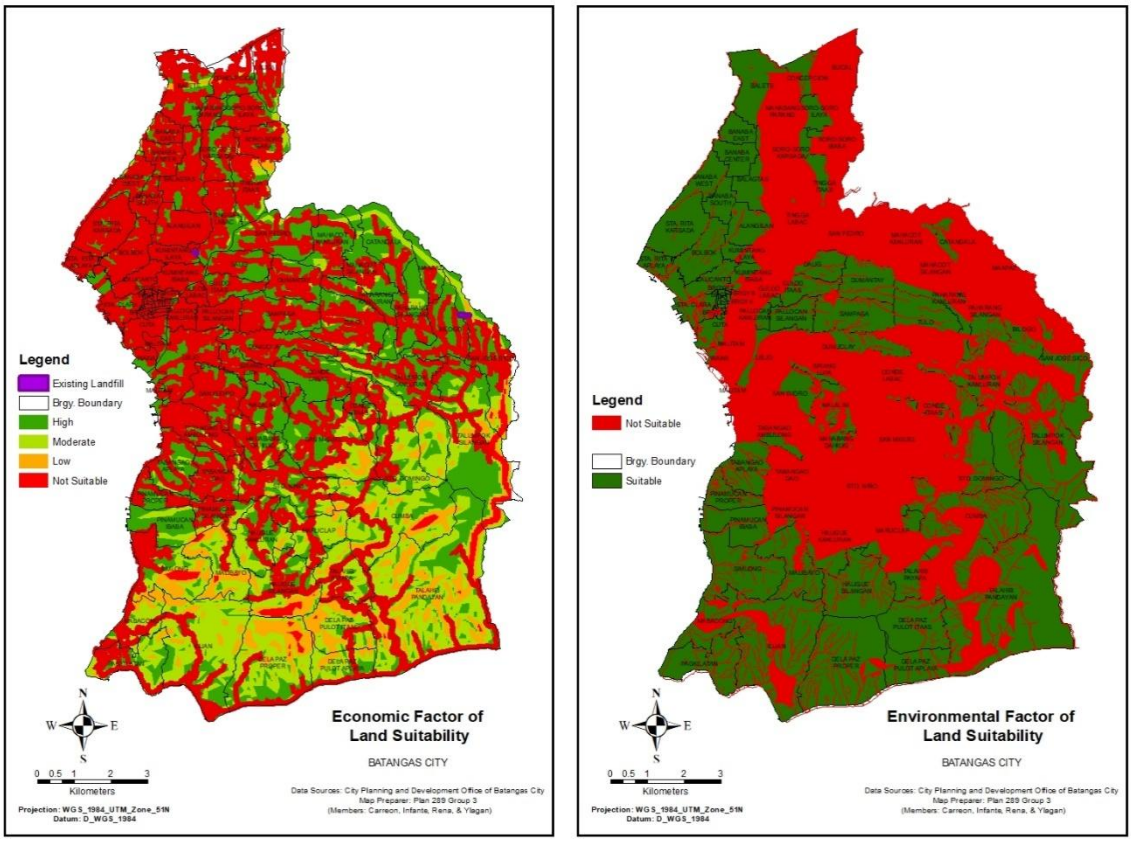

Figure 3.From left, economic & environmental criterion land suitability for SLFmap

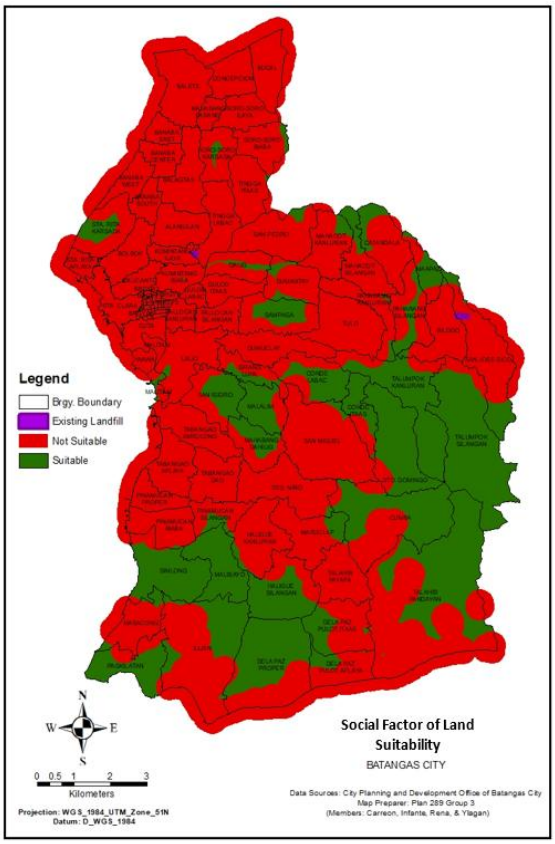

Figure 4.Social criterion land suitability for SLF map

C. Availability of Suitable land for new SLF facility in Batangas City

The site suitability map shows the best locations for new landfill facilities (see Figure 5). Three thematic maps (economic, environmental, and social) were overlaid to find suitable land for a new SLF facility in Batangas City. The percentage weight for each suitability component from a paired study was encoded in ArcGIS using spatial analysis tools to display appropriate landfill areas. Using the physical specifications in Table 3, Batangas City's total land area inappropriate for sanitary landfill sites is only 33500.17 hectares. The barangays with the most suitable land acreage include Catandala, Dalig, San Isidro, Sampaga, Sirang Lupa, Simlong, Paharang Silangan, Pagkilatan, and Sta. Rita Karsada and Haligi Silangan. However, relatively few barangays had consistently high suitability areas when the three criteria were weighted (refer to Table 6).

Integrating the weights derived from the AHP result and applying the GIS spatial overlay analysis tool using the thematic maps showed a fewhighly suitable areas for new landfill sites. However, the overlay analysis showed that the existing landfill facility site was unsuitable, providing scenarios with various factors which allow for the visualization and analysis of geographical data. This combination provides valuable information for decision-makers in the landfill site selection process, enabling them to make informed and reliable decisions.

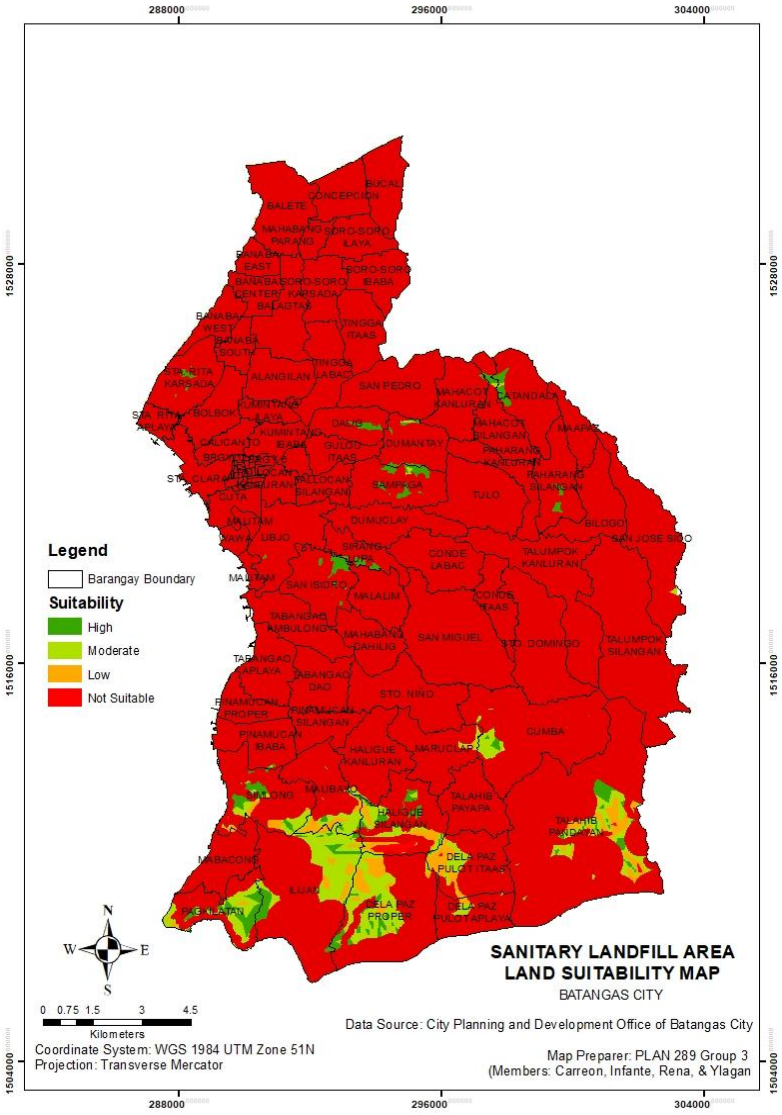

Figure 5. SLF site suitability map by Barangay

TABLE 6. BARANGAYS WITH HIGHLY SUITABLE AREAS FOR LANDFILL SITES

Highly Suitable Areas (Hectares)	
Barangays	**Area**
Dalig	14.06
Haligi Silangan	172.94
Ilijan	315.67
Sampaga	40.53
San Isidro	26.01
Sirang Lupa	14.01
Pagkalatan	164.49
Simlong	107.49
Total	855.2

IV. CONCLUSION

This study aimed to assess the land suitability for the current sanitary landfill facility of Batangas City and to evaluate potential sites for additional landfill facilities. The findings indicated that the existing LGU-owned sanitary landfill location is unsatisfactory due to its inadequate distance from key physical, economic, and environmental features. The city's growing population and expansion of built-up areas were found to negatively impact land suitability. Therefore, an option formanaging the current SLF is to consider incorporating safety design features to prevent environmental contamination and health risks to nearby settlements.The study also identified eight barangays with highly suitable sites for a new SLF facility. These 855.20 hectares of highly suitable land, which constitute only 0.00274% of the city's total area, are primarily located in the southern part of the city.The scarcity of landfill space in the city's northern part underscores the importance of adopting sustainable waste management practices to reduce waste generation and reliance on landfills [4].The limited area for new landfill facilities may increase the pressure on the city's existing SLF facility, leading to faster filling rates and potential operational challenges. Overloading these landfills can result in environmental degradation, including groundwater contamination, air pollution, and habitat destruction. Additionally, the scarcity of areas for sanitary landfill facilities poses challenges for urban planning, requiring the integration of new and complex landfill design considerations. This is essential to avoid scrutiny and opposition from local communities concerned about the impact of landfill facilities on their quality of life.

This study is limited to land suitability analysis for SLF facilities, considering only a few aspects related to the economy, environment, and physical characteristics of the city due to data availability. Other factors may affect the total availability of suitable lands. Despite the limitations, the spatial analysis process of this study reveals that the city may face a scarcity of land for new SLF sites and expect other implications related to limited suitable areas, such as provision for alternative waste management strategies to reduce waste production rates and environmental and health risks. As a result, this study challenges the city to evaluate the capacity of the eight barangays found with highly suitable sites and consider other variables that may affect land suitability, which were not included in this study. Moreover, this study highlights the need for the city to address the challenges associated with a comprehensive approach to waste management, community engagement, and investment in sustainable technologies, considering the urban expansion and proximity of the existing landfill facility site.

V. RECOMMENDATIONS

This study recommends that the local government of Batangas City should conduct an updated environmental impact assessment and community survey for settlements close to the existing landfill facility. This will help predict socio-economic and environmental impacts and determine whether the current waste disposal methods effectively avoid nuisances or hazards to public health and safety. It is also suggested that the current sanitary landfill facility consider investing in or adopting advanced waste management solutions. Additionally, the LGU is advised to conduct further studies on the capacity of the eight barangays with highly suitable sites for a new SLF facility for future management and risk mitigation purposes. An urban planning strategy should be developed to incorporate new landfill sites into land use planning, with careful consideration of proximity to residential areas, infrastructure, and environmental impacts. The city should address the implications of land scarcity for new SLF facilities by adopting sustainable waste management practices to reduce reliance on landfills. Moreover, it is recommended that policies be developed to manage landfill sites close to residential

areas, encourage knowledge dissemination and community engagement to support waste management and promote livelihood generation from waste. Investment in sustainable technologies to reduce overall waste generation is also essential.

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