Optimal Solid Waste Landfill Site Identification Employing GIS-Based Multi-Criteria Decision Analysis Within the Thach That District, Hanoi, Vietnam

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Abstract
The principal aim of this investigation was to identify optimal locations for solid waste landfill in the Thach That district of Hanoi. Employing Geographic Information System (GIS) and Multi-Criteria Decision Analysis (MCDA), nine thematic layers were assessed as pivotal criteria, including proximity to surface water, distance to historical and cultural sites, distance to rural population areas, proximity to waste collection points, current land use status, and slope. A Boolean logic model was applied based on the criteria outlined in the Vietnamese standard TCVN 6696: 2009, and Analytical Hierarchical Process (AHP) methodology was utilized for the analysis of the remaining criteria. The study results showed that 10,641.40 hectares were unsuitable, 7,867.60 hectares were less suitable and 220.89 hectares were suitable for a landfill, corresponding to 56.81%, 42.01%, and 1.18% of the study area, respectively. In terms of size, there are two unsatisfactory zones because the area is too small. Although the distance from suitable locations to some communes in Thach That district is quite far, about 20km, it is equivalent to the distance to the current. Therefore, these positions are accepted. This research has profound significance because it contributes to adding scientific basis for choosing landfill locations not only in Thach That district but also in Vietnam.

Keywords: AHP, GIS, Landfill Site Selection, MCDA, Solid Waste

1. Introduction

As outlined in the National Environmental Status Report spanning the period 2016 to 2020, Vietnam is experiencing a notable surge in the overall quantity of generated solid waste nationwide. Statistical estimates indicate an annual escalation in the range of 10-16% for solid domestic waste (SDW) in urban areas on a national scale. Industrial solid waste, quantified at 25 million tons per year, likely surpasses this figure due to underrepresentation, as industrial facilities beyond designated parks and clusters are incompletely accounted for. Ordinary solid medical waste production is approximately 96 thousand tons per year. The solid waste emanating from livestock activities and crop by-products is recorded at approximately 85-90 million tons and nearly 95 million tons per year, respectively [1].

In 2019, the total volume of SDW developed nationwide was 64,658 tons/day [2]. In most localities, the most common form of household waste treatment is landfilling, accounting for about 71%. In Hanoi City, the rate of landfilling SDW is 89%, the rate of burning (without generating electricity) is 11.0% [2]. The rate of industrial solid waste collected and processed reaches 90% of the generated volume. Most medical solid waste in hospitals is collected and classified daily at source. The application of solid waste treatment technologies is still limited [1]. In the Decision sanctioning the solid waste management plan for Hanoi Capital until 2030, with a perspective extending to 2050, it is stipulated that the capital city will be equipped with 17 solid waste disposal complexes [3].

Presently, however, only three operational solid waste disposal complexes exist: Nam Son Solid Waste Disposal Complex in Soc Son district, Xuan Son Solid Waste Disposal Complex in Son Tay town, and Cau Dien Solid Waste Disposal Complex in Nam Tu Liem district. Many wastes disposal complexes are behind schedule due to problems with site clearance. In Thach That district, the solid waste disposal complex in Lai Thuong commune was approved with an area of 4 hectares by 2020; In 2030, it will be 6 hectares; In 2050, it will be 11.8 hectares, but due to inappropriate location selection, people's complaints, and disagreement, it has not yet been implemented. can be constructed. On the other hand, in the district, there are spontaneous landfills on many roads and waste is jammed and overloaded at the dumps with all kinds of waste, from household waste to industrial waste (Commune Canh Nau, Huu Bang, Kim Quan, Di Nau, Chang Son, etc.) cause serious environmental pollution, affecting the landscape as well as people's lives. Therefore, it is extremely necessary to research and select a suitable solid waste landfill location in Thach That district.

Numerous countries globally have proactively engaged in the early planning of suitable locations for solid waste landfills due to the adverse impacts it poses on the environment, public health, society, and the economy. Addressing this intricate spatial analysis challenge is imperative for effective land use and urban planning. The complexity of the issue necessitates the evaluation of diverse criteria spanning nature, economics, society, and the environment [4]. Methodologically, multi-criteria analysis emerges as the most fitting approach, with Geographic Information System (GIS) serving as a potent decision support tool [5]. GIS facilitates the analysis and processing of spatial data, the computation of numerous criteria, and the integration of informational layers, thereby aiding in the identification of optimal landfill locations. Notably, a multitude of studies worldwide have successfully employed GIS and multi-criteria decision analysis (MCDA) methodologies for solid waste landfill site selection in various countries, including Thailand, India, Indonesia, Iran, Iraq, Turkey, Zambia, Pakistan, Ethiopia, among others [6] [7] [8] [9] [10] [11] [12] [13] and [14].

Multi-Criteria Decision Analysis (MCDA), also referred to as Multi-Criteria Decision-Making (MCDM), involves the process of decision-making when multiple criteria or objectives need to be collectively considered to rank or choose between alternatives. The applications of Multi-Criteria Decision Analysis (MCDA) primarily involve the evaluation of process impacts on the environment and aiding planning endeavors in determining optimal locations for specific purposes. The Analytic Hierarchy Process (AHP), developed in the late 1970s, has emerged as the predominant method within MCDA. AHP facilitates the determination of criteria weighting and alternative preferences by eliciting values through pairwise comparisons, rather than relying on direct numerical assessments.

Criteria for landfill location analysis are aggregated from diverse fields, encompassing binding environmental regulations, as well as natural and socio-economic conditions in the area. Spatial data, sourced from various outlets, is also incorporated. Research findings demonstrate that the amalgamation of Geographic Information System (GIS) and multi-criteria analysis amplifies the decision-making capacity of planners and relevant agencies in the selection of suitable landfill locations. This integrated approach contributes significantly to mitigating environmental concerns, including water contamination and public health degradation associated with inadequate waste disposal sites.

2. Materials and Methods

2.1 Study Area

Thach That district is a suburban district located northwest of Hanoi, a semi-mountainous area, with geographical coordinates from: 20º 56′45″ to 21º 06′10″ North latitude and 105º 23′30″ to 105º 38′22″ East longitude as shown in Figure 1. Thach That district is located in the Northern Delta, but is also a transition area between the Northern mountainous and midland regions and the plains. In general, the terrain gradually lowers from West to East and is divided into three main terrain types: Low mountainous terrain¸ accounts for 29.0% of the entire district area. Although the terrain slope is not large, compared to other regions in the district, it is much larger. The terrain is semi-mountainous and hilly, accounting for 46.0% of the entire district. The average height above sea level in this area is from 10m - 15m. In the area there are many independent, low, gentle hills, with an average slope of 30 - 80 degrees. Plain terrain, accounting for 25.0% of the entire district area. The terrain is quite flat, the average terrain height ranges from 5m - 10m above sea level.

The climatic conditions in Thach That exhibit characteristics of a tropical monsoon climate, characterized by high temperatures and humidity, accompanied by substantial rainfall during the summer and a dry, colder period in winter. The mean annual temperature stands at 23.4°C, with an average annual precipitation of 1,628mm.

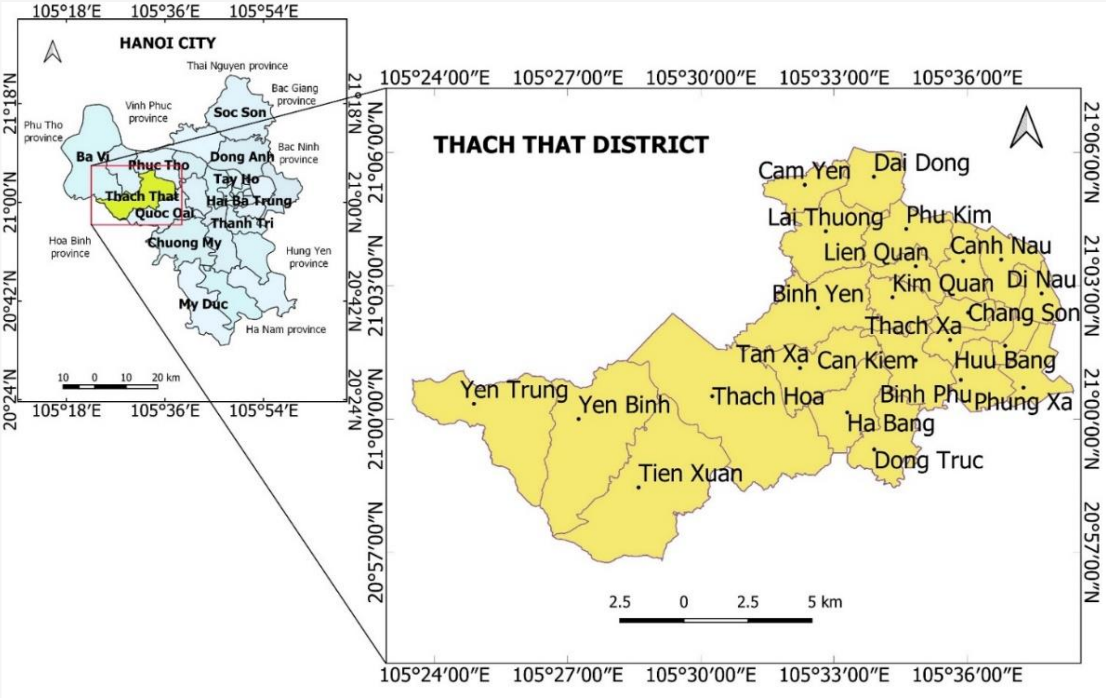

Figure 1: Thach That District, Hanoi, Vietnam

The region experiences an annual average of 1,680 hours of sunshine, while the prevailing air humidity is registered at 83.0%, with an annual evaporation rate of approximately 86.0mm. Notably, during the cold season from November to March of the succeeding year, the dominant wind direction is influenced by the Northeast monsoon. The remaining months of the year are dominated by Southeast winds. Occasionally, southwest winds appear in June and July. The district has 22 communes and 01 town with a district population of 253,786 people, and an economic growth rate of 13.6%. Economic structure: Industry and construction account for 69.2%; trade and services account for 25.0%; Agriculture, forestry, and fisheries account for 5.8%. Nowadays, this is the district with the most craft villages in Hanoi, with a rich and diverse system of craft villages, with a long tradition and famous nationwide. Currently, the district has more than 50 craft villages, of which 9 villages are recognized as traditional craft villages.

2.2 Data Collection

The investigation utilized QGIS3 and MicroStation V8i software in conjunction with both spatial and non-spatial datasets. The raster data employed a Digital Elevation Model (DEM) with a 30-meter resolution, obtained freely from the United States Geological Survey (USGS) website (https://earthexplorer.usgs.gov/).

Vector data layers were derived from the Thach That district's land use status quo map at a 1/10,000 scale, supplied by the Department of Natural Resources and Environment. Attribute data was gathered from specialized departments within the Thach That District People's Committee. The study employed the EPSG:5897 reference coordinate system, specifically VN-2000 / TM-3 zone 482 – Projected.

2.3 Methods

2.3.1 Criteria selection for suitable landfill site

The criteria were identified based on the Vietnamese standard TCVN 6696: 2009 - Solid wastes - Sanitary landfill - General requirements for environmental protection. This is a standard established by Vietnam's national technical standards committee established by the Ministry of Science and Technology of Vietnam. Members of the national standards technical committee include representatives of state agencies, science and technology organizations, societies, associations, businesses, other relevant organizations, consumers and experts. This standard stipulates general environmental protection requirements for the location, design, construction, operation and monitoring of environmental impacts after closure hygienic landfills for burying regular solid waste. This standard does not apply to hazardous solid waste landfills.

Moreover, the chosen criteria are grounded in prior scholarly investigations, the inherent natural and socio-economic conditions of the study area, and the capabilities of data collection. These criteria serve to delimit the placement of a landfill facility, with the overarching objective of preserving environmental integrity, public health, and various pertinent social considerations. There are three criteria identified from Vietnam standard 6696: 2009 distance to urban population area, distance to main roads (National highway, provincial road, highway) and distance to industrial zone [15]. The six criteria selected include distance to surface water, distance to historical and cultural sites, distance to rural population area, distance to waste collection points, land use status quo, slope.

a) Distance to Surface Water (Pond, Lake, River, etc.)

When choosing a landfill location, pay attention to leachate leakage and emissions that pollute water sources. Therefore, the distance from the landfill to surface water sources such as rivers, streams, ponds and lakes should be as far as possible [12].

b) Distance to Historical and Cultural Sites

Historical and cultural sites are very necessary and must be protected because they are extremely important in protecting the culture and traditions of a nation.

c) Distance to Rural Population Area

To protect the living environment of people in rural areas, landfills should be chosen in locations far from residential areas. Besides, the pollution of landfills does not affect the value of the land and the general development of the area in the future. Consequently, the appropriateness augments proportionally with the escalation of distance from human settlements.

d) Distance to Waste Collection Points

Waste collection points serve as intermediaries for the transference of solid waste from smaller collection vehicles to larger transport vehicles. When the distance to recycling facilities and landfills is considerable, direct transportation of accumulated waste becomes economically impractical. Hence, it becomes imperative to select landfills that are strategically positioned at an optimal distance from waste collection points.

e) Land Use Status Quo

Land use status quo provides information about the distribution of land and the current use of land resources such as agricultural land, forests, water surfaces, and special lands. This helps us protect and manage resources effectively.

f) Slope

The incline represents a pivotal consideration in the meticulous selection of a landfill site [12]. Terrains characterized by a gentle slope are adjudged as most optimal, receiving the highest evaluative ranking, primarily to alleviate landscaping expenditures and forestall the potential leakage of leachate. Conversely, steep gradients are considered unsuitable and are ascribed the lowest suitability values [16]. Additionally, the construction and upkeep of landfills on areas characterized by steeper inclines entail escalated financial outlays [17].

2.3.2 Multi-Criteria Decision Analysis (MCDA)

Multi-Criteria Decision Analysis (MCDA) involves the identification of criteria and the assignment of weights to factors according to their relative significance. Various MCDA methodologies find application in a spectrum of decision-making endeavors, encompassing the discernment of optimal landfill sites [12]. In this investigation, Boolean Logic, Analytic Hierarchy Process (AHP), and the Weighted Linear Combination method (WLC) were employed.

a) Boolean Logic

Boolean logic transmutes pertinent information from each input map into a binary format, denoted as either True or False, equivalent to the representation of 0 and 1 [18]. This transformation is encapsulated by Equation 1:

$$C = \{1 \text{ if class } A > \text{or} < X\} \text{ and } C = \text{class } A > \text{or} < X$$

Equation 1

In this methodology, the assumption is made that a site possesses suitability for a waste landfill. The determination of class quantity relies on the precision of the stipulated criteria, and the ultimate output expression is applied to each variable [19]. These variables are systematically employed to delineate two distinct classes, denoted as 0 and 1, signifying the designated suitable site and the resultant output in a new map, respectively. The resulting output map comprises two polygons, assuming a pivotal role in the context. Boolean Logic finds predominant application in the initial screening phases or in situations demanding the differentiation between impractical options and viable alternatives [20].

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This logic is employed when parameter maps are categorized into Boolean designations: suitable (yes) or unsuitable (no). The process involves the logical integration of binary maps derived from the application of conditional operators. When criteria and guidelines adhere to a set of deterministic rules, this method proves to be a pragmatic and straightforward approach. The outcome manifests as a binary map, categorizing each location as either satisfactory or unsatisfactory.

b) Application of Analytical Hierarchical Process (AHP)

AHP method, pioneered by Saaty, relies on pairwise comparisons to establish the relative importance of individual inputs. AHP simplifies intricate decision-making processes, particularly in situations where numerous factors need careful consideration [21]. This method transforms the intricate decision-making structure into a streamlined hierarchical system, utilizing pairwise comparisons to establish unilateral hierarchical relationships between ranks [12].

In accordance with antecedent investigations, coupled with an examination of local practical circumstances and expert consultations, efforts were directed toward formulating the pairwise comparison matrix. The evaluation of expert opinions was facilitated through the application of the Analytic Hierarchy Process (AHP) concept and Saaty's nine-point scale. Six-factor criteria, encompassing surface water, historical and cultural sites, rural population area, waste collection points, land use status quo, and slope, were utilized as input factors in the development of the pairwise comparison matrix. It was stipulated that the Consistency Ratio (*CR*) of the pairwise comparison matrix should not exceed 10% [21]. The Consistency Index (*CI*) is computed utilizing Equation (2):

$$CI = \frac{\lambda_{\max} - n}{n - 1}$$

Equation 2

In the provided equation, wherein n signifies the total count of criteria, λ_{max} denotes the maximum eigenvalue of the judgment matrix, a diminished Consistency Index (*CI*) implies a heightened consistency in the pairwise comparisons among the criteria [12]. Ultimately, the computation of the Consistency Ratio (*CR*) is achieved by dividing the CI by the ratio of the Random Consistency Index (*RI*), as depicted in Equation (3), employing the appropriate pre-established value for *n*.

$$CR = \frac{CI}{RI}$$

Equation 3

c) Weighted Linear Combination (WLC)

The final suitability map was generated by utilizing the results from the Analytic Hierarchy Process (AHP) in the Weighted Linear Combination (WLC) methodology. The WLC technique integrated the criteria weights derived from the pairwise matrix to calculate the suitability index value for prospective areas [12], as expressed in Equation (4):

$$S_i = \sum_{j=1}^{n} w_j x_{ij} C_j$$

Equation 4

In the context of Equation (4), S_i denotes the suitability index for area *i*, w_j signifies the relative importance weight assigned to criterion *j*, x_{ij} represents the grading value of area i pertaining to criterion j, and n stands for the overall count of criteria. The constraint's score, Cj, assumes values of either 0 or 1 [22]. The amalgamation of factor maps was executed to guarantee consistent scaling for the Weighted Linear Combination (WLC) analysis. The standardization of maps was carried out in QGIS3 using the spatial analyst tool "reclassify." Each criterion's classes were assigned rankings from 1 to 4, designating 1 as unsuitable, 2 as less suitable, 3 as suitable, and 4 as highly suitable. Subsequently, the standardized criteria underwent amalgamation through weighted overlay analysis, yielding a landfill site suitability map for the investigated area. The identification of appropriate landfill sites, along with their respective suitability levels, relied on high-quality data sources delineated in Table 1 and Table 2, substantiated by relevant scientific literature. The comprehensive framework of the research study analysis is depicted in Figure 2. It is noteworthy that slope data is stored in raster format, while other data is stored in vector format due to extraction from the district-level land use status quo map.

3. Results and Discussion

3.1 Locating of Landfill using Boolean Logic

Based on TCVN 6696:2009, Solid waste landfills are classified by area as follows: Small landfills with an area of less than 10 hectares; Medium, large, and very large landfills have an area of from 10 to 30 hectares, from 30 to 50 hectares, and greater than or equal 50 hectares, respectively. For small and medium landfills, TCVN 6696:2009 has six regulations related to environmental safety distance when choosing a landfill.

Table 1: The distance criteria and their suitability ranges [15]

Criteria	Unsuitable	Suitable
Distance to urban population area	0 – 3,000m	> 3,000m
Distance to main roads (National highway, provincial road, highway)	0 – 100m	> 100m
Distance to industrial zone	0 – 1,000m	> 1,000m

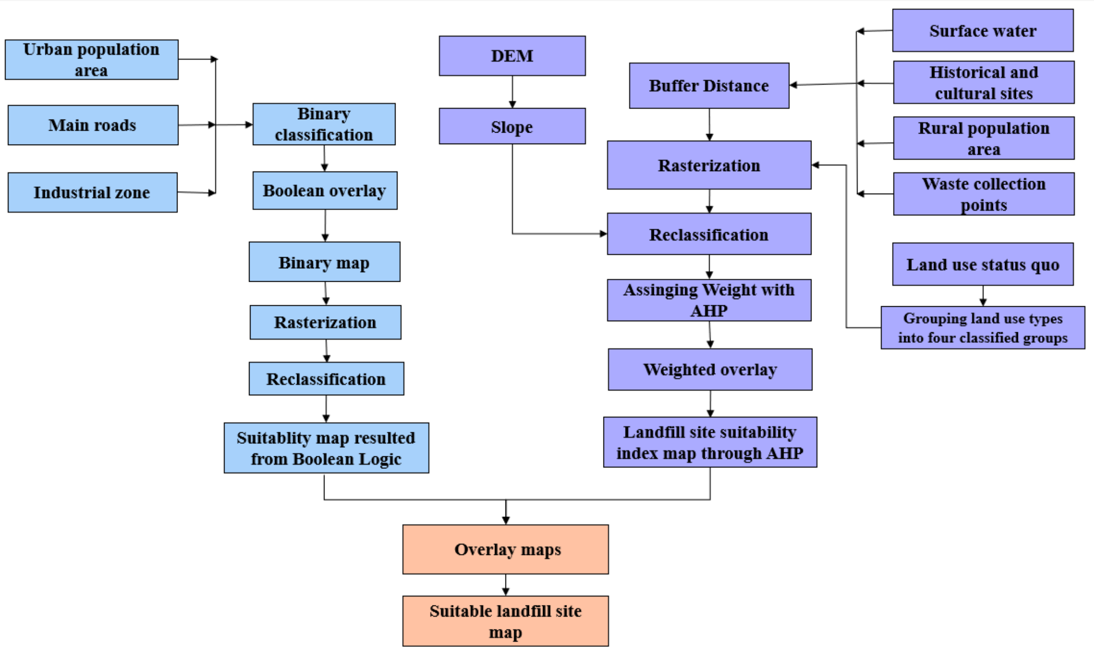

Figure 2: Methodological flowchart

However, in Thach That district there are no airports, harbors, underground water exploitation projects and mountainous residential clusters. Therefore, three criteria are identified as shown in Table 1.

Establishing a buffer zone encompassing a radius of 3,000 meters around the urban population area layer, a 100-meter buffer zone for main roads, and a 1,000-meter buffer zone around the industrial zone layer was undertaken. The standardization of criteria map layers employed Boolean logic. The Boolean algorithm partitioned the study area into appropriate and inappropriate categories, effectively segregating regions with potential for landfill site establishment from other areas. This methodological approach serves to systematically delineate suitable locations based on specified criteria, fostering a rigorous and objective decision-making process. The output map in Figure 3 has two regions: Suitable and unsuitable region. Convert data to raster format and reclassify with cell size of 0.5m.

The results reveal that cumulatively 10,677.85 ha representing 59.94% of the study area is unsuitable, while 8,074.61 ha representing 40.06% is suitable.

3.2 Application of AHP in Siting Solid Waste Landfill

In the present investigation, a comprehensive approach was adopted, leveraging scholarly literature, documentary resources, and expert interviews to ascertain the priority and relative importance of each criterion, as detailed in Table 2 and Table 3. The total area corresponding to the suitability of each criterion is systematically categorized, with suitability ranks assigned as follows: 4 for highly suitable, 3 for suitable, 2 for less suitable, and 1 for unsuitable. Within the Vietnamese context, a land use status quo map serves to depict the spatial distribution of various land types at a specific temporal point, crafted in accordance with administrative units.

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Table 2: The criteria and their suitability ranges

Criteria	Unit	Class	Value	Suitability	Source
Distance to surface water (pond, lake, river, etc.); SW	m	0 – 500	1	Unsuitable	Biru and Endalew [14] Phuong et al., [24]
		500 – 1,000	2	Less suitable	
		1,000 – 2,000	3	Suitable	
		> 2,000	4	Highly suitable	
Distance to historical and cultural sites: HC	m	0 – 1,000	1	Unsuitable	Laon et al., [5] Kareem et al., [10]
		1,000 – 3,000	2	Less suitable	
		3,000 – 5,000	3	Suitable	
		> 5,000	4	Highly suitable	
Distance to rural population area: PA	m	0 – 500	1	Unsuitable	Roy et al., [7] Biru and Endalew [14]
		500 – 1,000	2	Less suitable	
		1,000 – 2,000	3	Suitable	
		> 2,000	4	Highly suitable	
Distance to waste collection points: CP	m	> 6,000	1	Unsuitable	Laon et al., [5]
		4,000 – 6,000	2	Less suitable	
		2,000 – 4,000	3	Suitable	
		0 – 2,000	4	Highly suitable	
Land use type: LU		Other types	1	Unsuitable	Phuong et al., [24]
		Forest land	2	Less suitable	
		Agricultural land	3	Suitable	
		Unused land	4	Highly suitable	
Slope:SL	Degree	15 -50	1	Unsuitable	Kareem et al., [10] Mvula et al., [12]
		10 – 15	2	Less suitable	
		5 – 10	3	Suitable	
		0 – 5	4	Highly suitable	

Table 3: Pairwise comparison matrix

Criteria	SW	HC	PA	CP	LU	SL
SW	1.000	0.500	0.333	2.000	0.333	0.333
HC	2.000	1.000	0.500	3.000	0.250	0.333
PA	3.000	2.000	1.000	5.000	1.000	0.500
CP	0.500	0.333	0.200	1.000	0.200	0.200
LU	3.000	4.000	1.000	5.000	1.000	0.500
SL	3.000	3.000	2.000	5.000	2.000	1.000
Sum	**12.500**	**10.833**	**5.033**	**21.000**	**4.783**	**2.867**

The National Assembly of Vietnam exercises regulatory control over land classification through the Land Law - Law No. 45/2013/QH13 of 2013. Based on usage objectives, land is classified into three primary groups: Agricultural land, Non-agricultural land, and Unused land. These groups further subdivide into distinct land use types, exemplified by agricultural land encompassing categories such as land for the cultivation of annual crops (including paddy land and land for other annual crops), land for perennial tree cultivation, production forest land, protective forest land, special-use forest land, aquaculture land, among others [23].

For the purpose of reducing site clearance costs and protecting forests, the study divided land into four groups as follows: Agricultural land, forest land, unused land and other types of land [24]. Maps were generated through buffer analysis for each criterion. Subsequently, the data underwent conversion to raster format with a cell size of 0.5 meters, followed by reclassification assigning four numeric values (1, 2, 3, and 4) to denote areas as not suitable, less suitable, suitable, and highly suitable. Each criterion was then assigned a weight proportional to its respective percentage of influence shown in Figure 4.

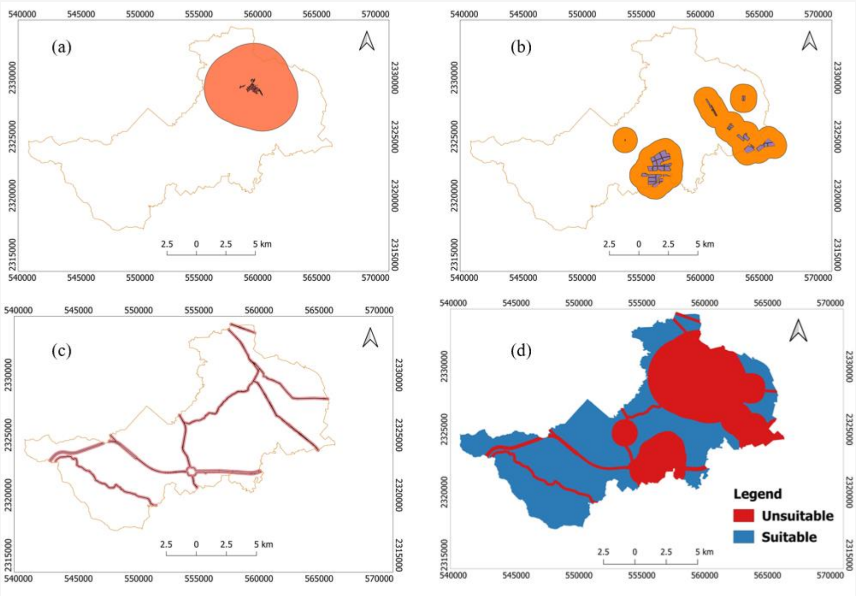

Figure 3: Constrain maps

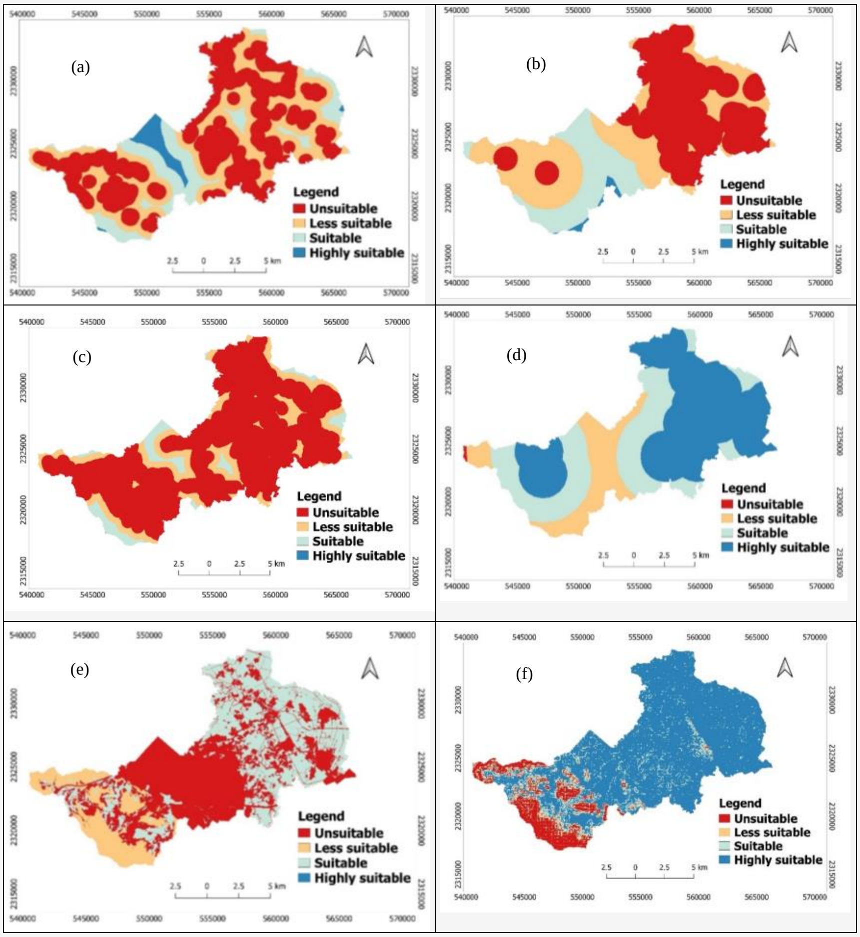

Figure 4: Criteria for suitable landfill site selection, (a) Distance to surface water, (b) Distance to historical and cultural sites, (c) Distance to rural population area, (d) Waste collection points, (e) Land use status quo, (f) Slope

Through overlaying these weighted criteria, a suitability map was generated, capturing the diverse degrees of significance these criteria hold in the identification of an appropriate solid waste disposal site. The outcomes of the overlay analysis resulted in the categorization of results into four distinct classes, delineating varying levels of suitability for potential waste disposal locations.

The findings reveal that, with the exception of the slope, waste collection points, all other factor criteria collectively designate less than 5% of the study area as highly suitable for landfill establishment. Specifically, no region meets the criteria for high suitability under the rural population area criterion, with 6.42% classified as suitable, 16.67% as less suitable, and the remaining 76.91% deemed unsuitable. Likewise, the analyzed area demonstrates minimal high suitability for landfills under the surface water, land use status quo, and historical and cultural sites criteria, constituting 3.7%, 0.07%, and 0.85%, respectively.

Further scrutiny reveals that, under the surface water criterion, 14.70% of the area is classified as suitable, 29.93% as less suitable, and the remaining 51.67% as unsuitable. Concerning the land use status quo criterion, 39.43%, 13.39%, and 47.11% of the research area are categorized as suitable, less suitable, and unsuitable, respectively. The historical and cultural sites criterion designates 18.4% of the study area as suitable, while 32.13% and 48.62% are deemed less suitable and unsuitable. The slope of the study area is generally gentle, explaining why 75.98% of the area is classified as highly suitable based on the slope criterion conditions in this study. The waste collection points criterion designates approximately 51.31% of the study area as highly suitable for a landfill, with 32.23%, 16.3%, and 0.16% classified as suitable, less suitable, and unsuitable, respectively. In accordance with Saaty's AHP method, the consistency ratio formula (equation 3) employs a constant value of RI (Random Consistency Index) set at 1.25 for six parameters. To maintain judgment consistency, the ideal consistency ratio value is less than 0.1 or < 10%. In this specific scenario, the calculated Consistency Ratio (CR) is 0.029, signifying a state of perfect consistency shown in Table 4 and Table 5.

Therefore, the entirety of the judgments derived from the pairwise matrix in AHP is deemed valid for the purpose of selecting a suitable landfill site in Thach That district. The cartographic output generated via the AHP revealed that 2,990.25 hectares, constituting 15.97% of the study area, were categorized as unsuitable shown in Figure 5. Furthermore, 15,423.84 hectares, accounting for 82.35% of the study area, were identified as less suitable, while 315.80 hectares, equivalent to 1.69% of the study area, were deemed suitable for a landfill. Detailed results are shown in Table 6. Realizing the significant difference between the area suitable for landfill according to Boolean logic with TCVN 6696:2009 and AHP analysis, specifically the percentage of suitable area for the two methods is 56.94% and 1.68%, respectively. This proves that selecting solid waste landfill locations based only on TCVN 6696:2009 is not enough.

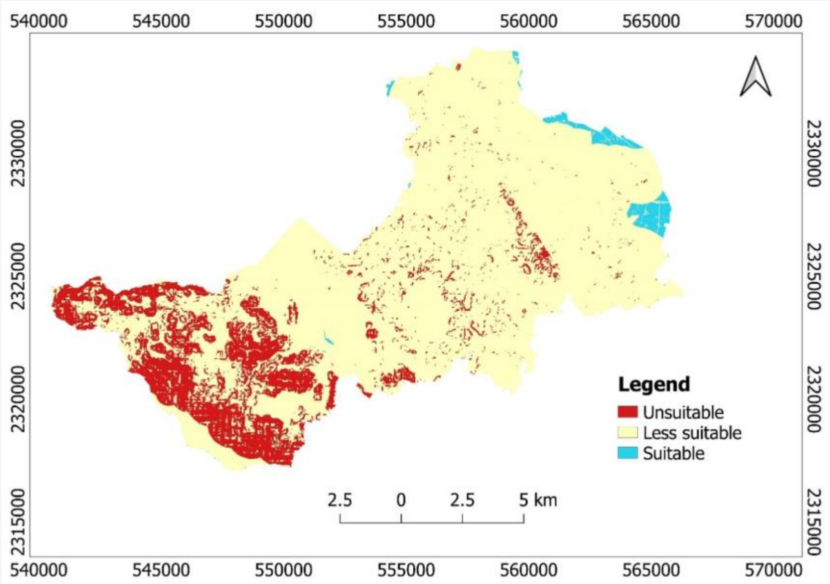

Figure 5: Landfill site suitability index map through AHP

Table 4: Criterion weights after applying AHP comparison matrix

No.	Criteria	Criteria weights	%
1	Distance to surface water	0.079	7.9
2	Distance to historical and cultural sites	0.111	11.1
3	Distance to rural population area	0.207	20.7
4	Distance to collection point	0.045	4.5
5	Land use type	0.238	23.8
6	Slope	0.320	32.0
	Sum	1.000	100.0

Table 5: Consistency assessment outcomes

λ_{max}	*n*	*RI*	*CI*	*CR*	Consistency
6.180	6	1.25	0.036	0.029	Satisfactory

Table 6: The suitability level and corresponding percentage coverage of the total area

Suitability	Area (m^2)	Area (ha)	Area (%)
Unsuitable	106,413,973.3	10,641.40	56.81
Less suitable	78,676,038.25	7,867.60	42.01
Suitable	2,208,884.75	220.89	1.18

Table 7: Area of suitable zones

ID	Area (m^2)	Area (ha)	Communes
1	79,8459.1	79.85	Canh Nau
2	75,220.5	7.52	Di Nau
3	946,695.0	94.67	Di Nau
4	139,760.9	13.98	Huu Bang
5	200,692.2	20.07	Phung Xa
6	42,278.5	4.23	Tien Xuan
7	11,141.1	1.11	Binh Yen
8	82,617.1	8.26	Cam Yen
9	92,406.6	9.24	Dai Dong

3.3 Landfill Suitability Map for Thach That, Hanoi

Finally, performing overlay classification with two maps resulting from Boolean logic model and AHP analysis. This is a combination of mandatory conditions according to regulations issued by the Ministry of Science and Technology and selection criteria to determine the most suitable location of the landfill. The resulting map is shown in Figure 6. The suitable area is 220.89 hectares, accounting for 1.18% of the total area. These areas are located in the following communes: Canh Nau, Di Nau, Huu Bang, Phung Xa, Tien Xuan, Binh Yen, Cam Yen, Dai Dong. Creating suitable zones based on the boundaries of suitable areas (including traffic land) obtaining 9 areas shown in Figure 7.

The results show that there are five suitable zones with an area of less than 10 hectares each, of which the two smallest areas are located in Binh Yen commune and Tien Xuan commune with an area of 1.11 hectares and 4.23 hectares respectively. These two smallest areas are not suitable for solid waste landfills. The areas of nine suitable zones are shown in Table 7. In Di Nau, Cam Yen and Dai Dong communes, landfills with suitable areas of 7.52 hectares, 8.26 hectares and 9.24 hectares respectively. These three areas are suitable for building small landfills. These three areas are suitable for building small landfills. The remaining four areas in Huu Bang, Phung Xa, Di Nau, and Canh Nau communes are suitable for medium landfills.

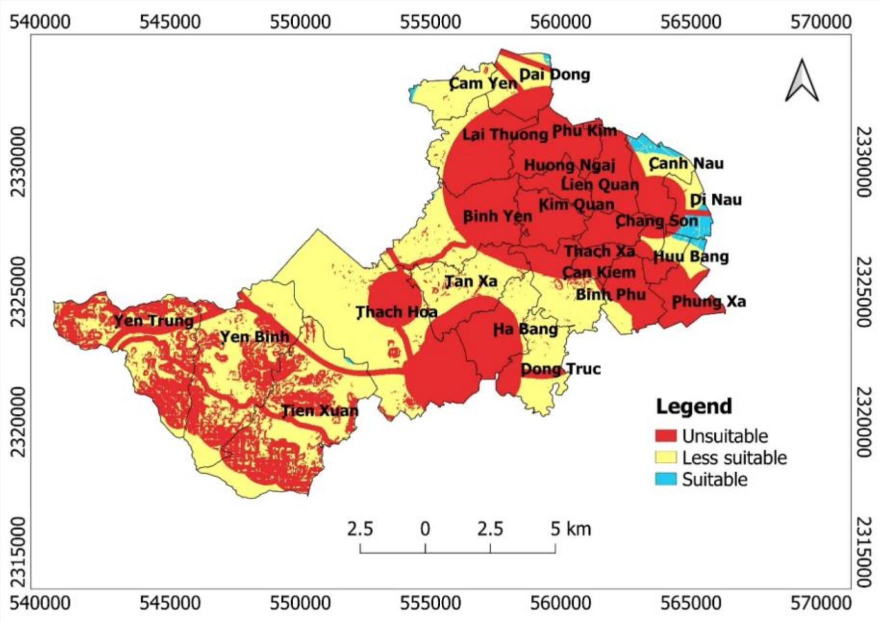

Figure 6: Landfill site suitability map in Thach That district, Hanoi

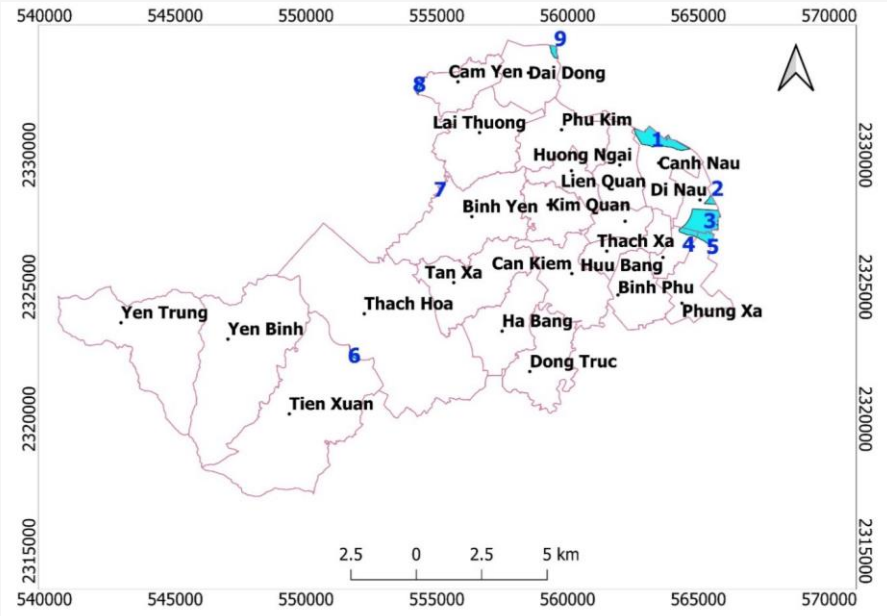

Figure 7: SWL Suitable zones

4. Conclusion

A suitability map for landfill sites in Thach That district, Hanoi city, was generated through the application of GIS and MCDA. The three identified criteria are based on the standards specified in the Vietnamese standard TCVN 6696: 2009 such as distance to urban population area, main roads, industrial zone; combined with six criteria related to actual local conditions and data that can be collected such as distance to surface water, historical and cultural sites, rural population area, collection points, land use status quo and slope. The study results showed 10,641.40 hectares representing 56.81% of the investigation area was unsuitable, 7,867.60 hectares representing 42.01% of the investigation area was less suitable and 220.89 hectares representing 1.18% of the investigation area was suitable for a landfill. Suitable locations for solid waste landfills are located in communes such as Canh Nau, Di Nau, Huu Bang, Phung Xa, Dai Dong, Cam Yen and Tien Xuan. Among them, the locations with

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the largest area and highest suitability index are located in Di Nau and Canh Nau communes. In Lai Thuong commune, there is no suitable location to choose as a solid waste landfill. This shows that the planning of solid waste landfills in 2011 here is not appropriate.

Considering the size of the landfill, there are two areas that are not suitable because the area is too small. Of the remaining seven zones, there are three zones suitable for small landfills and four zones suitable for medium landfills. Although the distance from suitable locations to some communes in Thach That district is quite far, about 20km, it is equivalent to the distance to the current landfill in Xuan Son commune and Son Tay town. Therefore, these locations are suitable for solid waste landfills in Thach That district in particular and Hanoi city in general. This research is highly significant as it contributes to the ongoing knowledge regarding the selection of suitable landfill sites in developing countries, emphasizing both scientific credibility and social acceptance. Moreover, the findings have the potential to offer valuable insights to the administrators and planners of Hanoi city, assisting them in identifying an appropriate site for solid waste landfill and addressing challenges related to solid waste management administration.

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