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Original Research

Appropriate Disposal Site Selection for Urban Solid Waste Management using Geospatial Technique: A Case Study of Haramaya Block, Eastern Ethiopia

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Abstract

Solid waste management is a pressing issue in the world, particularly in developing countries like Ethiopia, due to rapid population growth, inadequate site selection, and ineffective management systems. This study aimed to locate suitable sites for urban solid waste management in Haramaya Block, Eastern Ethiopia, using geospatial techniques. Multiple criteria, including land use and land cover, built-up areas, slope, elevation, road network, lake, drainage, protected area, and soil texture, were considered. These criteria were integrated into a Geographic Information System (GIS) environment, and their weights were determined using the Analytical Hierarchy Process (AHP) and pair-wise comparison matrix. Additionally, weighted overlay analysis in ArcGIS was employed to evaluate the suitability of different areas. The findings indicated that the study area comprised unsuitable, moderately suitable, suitable, and highly suitable zones, accounting for 20%, 57%, 19%, and 4% of the area, respectively. Majority of the area (57%) was classified as moderately suitable for waste disposal. Approximately 20% were deemed unsuitable, while 19% and 4% were identified as suitable and highly suitable, respectively. The potential dumpsite zones with high to very high suitability were mainly concentrated in the eastern, northeastern, and southwestern parts of Haramaya. These areas overlapped with moderately and highly suitable potential zones, influenced by factors such as land use, proximity to roads, built-up areas, lakes, and slopes (accounting for 32%, 20%, 16%, 11%, and 8%, respectively). Identifying these recommended suitability classes will contribute to the establishment of socially acceptable, economically viable, and ecologically sustainable dumpsites in the study area.

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INTRODUCTION

Any kind of garbage, trash, refuse, and abandoned physical goods are referred to as "solid waste (SW)," which can be divided into different categories depending on where it was produced, such as municipal solid waste (MSW), health care waste, or e-waste (Kaza *et al.*, 2018; World Bank Group, 2020). The majority of municipal solid waste (MSW) is composed of wastes that are often created by residential, commercial, and institutional operations, such as food waste, paper waste, plastic waste, glass waste, textile waste, scrap wood waste, and other goods that are unwanted and disposed (Ashani *et al*., 2020; Wang *et al*., 2017). Global waste generation rates are increasing due to several reasons (Chatterjee & Mazumder, 2019), such as the continuous rise in world population, growing industrialization, and steady improvement across the world which have led to a drastic increase in a tremendous quantity of waste production.

According to estimates, the yearly production of SW in 2020 was estimated to be 2.24 billion tonnes, resulting in 0.79 kg per person per day and this will rise by 73% from the 2020 levels, reaching 3.88 billion tonnes in the next 30 years. Since human activities are still taking place, both the quantity and rate of SW will continue (World Bank, 2022). Despite being created daily by individuals living in both urban and rural places all around the world, the urban SW draws attention. With Urbanization and population growth, large amounts of SW are created in metropolitan areas, making it difficult and complicated to control SW effectively (Ravichandran & Venkatesan, 2021).

Urban ecosystems around the world are facing significant challenges as a result of poor management and unsuitable SW management, which have a detrimental effect on both the environment and human health (Bahukhandi & Ollemman, 2022; Naveen & Sivapullaiah, 2020; Singh, 2019). Ineffective municipal solid waste management (MSWM), which hurts aesthetics, human health, and the ecosystem internationally, is the root cause of the worst environmental and social catastrophes (Alemayehu, 2022). In most village locations of developing nations, the bulk of MSW is illegally dumped and disposed of in open areas, drains, water bodies, and along highways that stretch outside the village's boundary. By blocking streams and drainage systems, MSW plays a significant role in urban floods by providing an ideal environment for mosquito breeding. Furthermore, trash, particularly plastics, is burned outside, posing a pollution and health risk (Glotko *et al*., 2019; Stroiteleva *et al*., 2020).

Ethiopia faces several obstacles that prevent the country from creating a sustainable strategy for waste management, including those related to technology, the economy, community, institutions, and the law. Urban waste management in the county is now uneven, insufficient, and ineffective, which points to sporadic and irregular collection, sparse coverage, technological issues, and a lack of law enforcement. More than half of the population burns their garbage in the open. The open disposal of wastes without any kind of procedural facilities is a common practice, and it frequently results in a mixture of toxic waste, which is a major issue for both human health and ecological issues (Balew *et al*., 2020; Teferi, 2022; Teshome, 2021).

One of the root causes of serious human health and environmental issues through the spread of disease, the creation of breeding grounds for danger vectors, the risk of fire, environmental pollution, aesthetic irritability, and monetary losses is improper management of significant SW quantities generated by routine activities in the nation's household, commercial, and industrial sectors (Kebede *et al*., 2021). Similar issues are present in the study area, and the SWM problem is one of the area's most urgent issues at the moment. For example, the amount of SW produced by Haramaya University is estimated to be 3,509.08 tonnes per year. There are frequently insufficient scientific waste disposal techniques in this area (Kassaye, 2018). Haramaya town of the study area is one of the lakeside community settlements in Ethiopia (Kabiso *et al*., 2022). Growing trends of urban expansion and industrialization with a lack of proper waste management systems in the country, have raised concerns about the pollution of water bodies, particularly lakes (Berehanu *et al*., 2015; Zinabu & Pearce, 2003). Hence, unscientific SW disposal which does not act by environmental disciplines in the study area is likely to cause a potential hazard and may pose a considerable risk to the marine ecosystem and surrounding environment.

A disposal site facility is one of the most important and appropriate MSWM hierarchies usually used in municipalities across the globe (Adipah & Kwame, 2018; Yakubu & Zhou, 2018). It is more popular than other management systems in many poor countries because of its easier accessibility and less labor-intensive technique designed for the safe disposal of SW (Aslam *et al*., 2022; Hantoko *et al*., 2021; Nanda & Berruti, 2021). The need for a proper and scientific management approach is essential to provide a decent existence in low-incoming nations (Cobos-Mora *et al*., 2022) by avoiding open or illegal dumping of SW in improper places(EPA, 2020). As a result, choosing a SW disposal site becomes one of the most crucial steps in urban waste management (Bilgilioglu *et al*., 2022)**,** and proper disposal site is the best way to protect public health, reduce environmental impact, and ensure the long-term isolation of MSW deposited in the disposal site (BC Ministry of Environment, 2016).This is influenced by factors such as physical conditions, distance from other areas, current and future land use, sensitivity of the receiving environment, and disposal site size (BC Ministry of Environment, 2016; Roy *et al*., 2022).

As a result, different locations throughout the world have conducted studies on the use of GIS to find potential trash disposal sites. Given that wastelands outside of urban areas are seen to be the greatest sites to dispose of wastes, determining the optimal locations for the disposal of solid waste in urban areas is a complicated issue in the majority of countries(Bengal *et al*., 2022). The expanding environmental challenges connected to garbage disposal have also been managed using RS and GIS. Processes for managing garbage can be made more effective by effectively utilizing GIS and RS technology. When locating trash disposal sites, such as disposal sites, and when figuring out environmentally suitable disposal options, these techniques were most frequently used (Singh, 2019). However, no research identifying MSW dump locations for the Haramaya block has been done.

This highlights the knowledge gap that the present study is attempting to fill. These issues are significant obstacles that call for action in order to improve the socio-environmental setting. To find appropriate disposal sites, it's crucial to pay close attention to the area's poor management situation. Thus, a new, safer hierarchical approach to SWM planning must be adopted by municipalities. This study's main goal was to identify appropriate locations for the management of MSW in the Haramaya block of eastern Ethiopia using geospatial methods. Therefore, the main objective of this study was to assess appropriate disposal site selection for urban solid waste management using geospatial technique: A case study of Haramaya Block, Eastern Ethiopia

MATERIALS AND METHODS

Study area

Haramaya Block is a community development area that forms administrative subdivisions including towns (Haramaya, Bati, and Didimtu) and the Haramaya University. The study area is located in the Haramaya district, which is a part of the Eastern Hararghe Zone in the Oromia National Region State of Ethiopia. Haramaya is situated along the main road at 505 km east of Addis Ababa, the capital city of Ethiopia. Geographically, the area lies between 828000–840000 min east and 1032000–1047000 min the north and its elevation ranges from 1972 to 2303 meters above sea level (Figure 1).

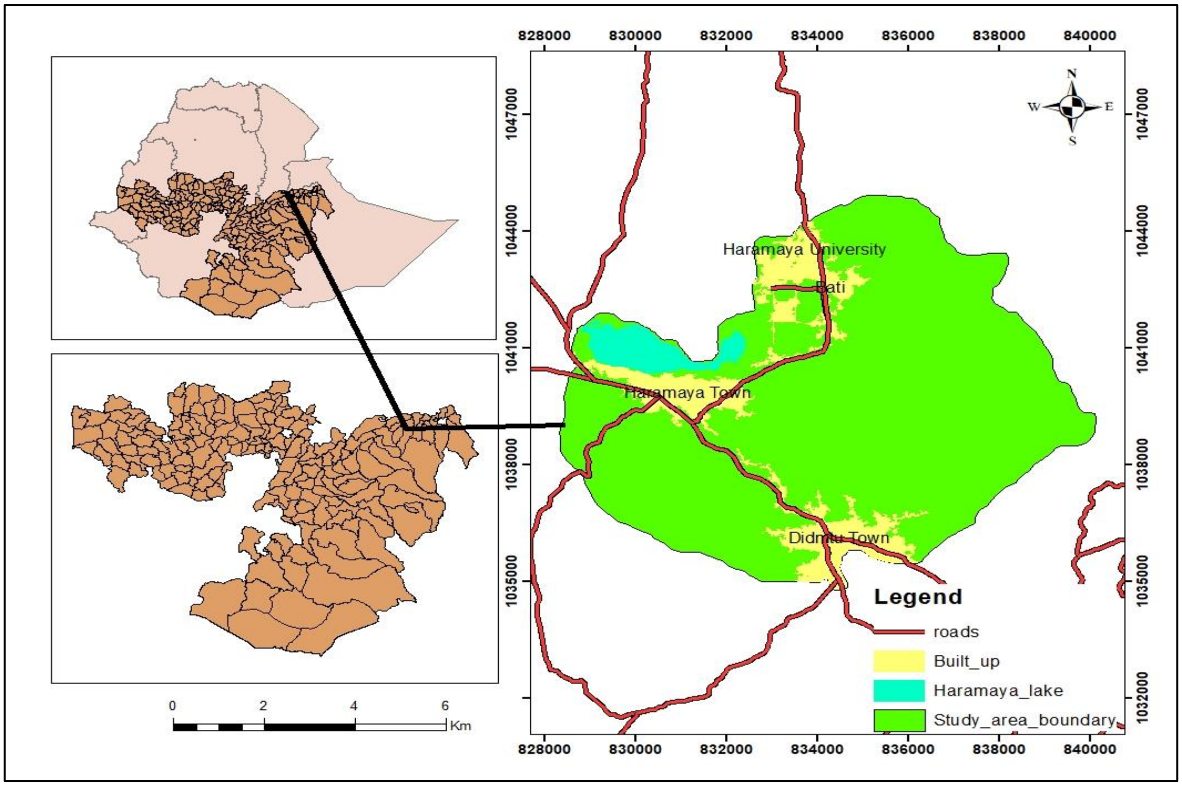

Figure 1: Local map of the study area.

According to the Ethiopian National Meteorology Agency, the area is located in environments that receive the mean annual rainfall and mean minimum and maximum temperatures of 800.9 mm, 9.9 ºC, and 24.18 ºC, respectively, for the last 2014. According to information obtained from the Haramaya Municipalities (2023), the total population of the area is 119,068 which has a rapidly increasing rate of population growth. In line with this population growth, considerable expansions of different residential housing, institutional, and commercial buildings were increasing, which in turn added a huge amount of municipal solid waste to these development areas.

Selection of the key factors and their data sources

It is very important to be reasonable in selecting key factors to get an appropriate site for solid waste disposal. The variables considered in one area may not be sensitive in other places based on actual topographic characteristics, settlement spatial distributions, and hydrological patterns. The criteria for site selection were mainly focused on the detection of the suitability of potential disposal site sites, and modifications to on-land facilities require an inclusive assessment of site conditions and potential impacts on the environment. According to Özkan *et al*.(2020)**,** various factors related to the environment, society, and economy need to be taken into account when selecting a disposal site**.** These factors include the availability of resources, the physical environment, and natural events, which significantly influence the criteria used for choosing a suitable disposal location. During the construction process, it is crucial to consider factors such as the required land size, accessibility for transportation, the physical environment including topography and climate conditions, environmental protection measures, and hydrogeological conditions (Josimovi & Mari, 2012)**.** Furthermore, scientifically, a dumping site may not be in urban or agricultural areas according to urban management and planning standards. Not only that, it may not be highly isolated from roads and drainages. It should be away from lakes in particular (Tadese *et al*., 2022). Therefore, disposal sites need to be placed at a range that will have the minimum negative impact on the environment and human health.

Based on these standards, the significance of these criteria, and the availability of data for the Haramaya disposal site sitting in development areas, about nine (9) key factors, which include LULC, settlement, slope characteristics, road networks, proximity to the lake, drainage patterns, proximity to protected areas, elevation characteristics, and soil textures, were considered in this study. Consequently, appropriate sites were generated using multi-criterion analysis on the ArcGIS 10.8 platform. To generate a pair-wise comparison matrix**,** key factors were prioritized and weighted according to their actual importance and influence in indicating appropriate dumping sites. Thus, to assess these factors, different data sources, which are summarized below in Table 1, were used.

Table 1: Summarized data with the sources and spatial/temporal resolution

S/N	Parameters	Sources	Description
1	Land use land cover	Sentinel 2 satellite image downloaded from www.usgs.gov or http://glovis.usgs.gov	
2	Built up	Generated from Sentinel 2(10*10m)	
3	Slope	Generated from DEM (12.5 × 12.5)	
4	Road Networks	https://data.humdata.org/dataset/wfp-geonode-ethiopia-road-network-main-roads/resource/ff973cb8-6d22-40c2-88e8-70ed4c882cba	
5	Surface water	Extracted from Sentinel 2(10m*10m)	
6	Drainage network	Generated from DEM (12.5 × 12.5)	
7	Protected areas	Digitized from Aerial photo of Shambu town	
8	DEM	https://search.asf.alaska.edu/	(12.5m×12.5m)
9	Soil	Ministry of Water, Irrigation and Energy	2022

Materials/Software used

In this study, a variety of tools and applications were employed effectively. GPS was utilized to get the ground data needed to evaluate the precision of classified satellite photos. The satellite images were analyzed using the ERDAS Imagine 15 program, and the parameter and overlay analyses were combined using Arc GIS 10.8. IDRISI Andes 15 software is also necessary for pair-wise comparison and multi-criteria evaluation.

Methods of Data Analysis

Analytic Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) is widely recognized as a highly effective multi-criteria decision technique used across various fields. When it comes to selecting suitable dumping sites, the AHP takes into account an extensive range of physical land features, such as terrain, infrastructure alignment, settlement patterns, surface water, topography, geology, soil texture, and socially protected areas. The AHP initiates the decision-making process by evaluating and assigning weights to each factor, which helps determine their relative significance. This is achieved through a pair-wise comparison matrix that provides a comprehensive overview of the relevance of each parameter. The weights are derived by calculating the principal eigenvector of the matrix. These factors and their resulting weights are then utilized as input for the Multi-Criteria Evaluation (MCE) module, employing weighted linear combination overlay analysis. Before the overlay analysis, the layers are standardized to a common scale.

Assigning each dataset a suitability value ranging from 1 to 4 (with 1 representing unsuitability and 4 representing high suitability) enables proper combination for overlay analysis (Town *et al*., 2019). The resulting factors and their weights are fed into the MCE module, facilitating the weighted linear combination overlay analysis. Additionally, to ensure accuracy, the consistency and coherence of the pair-wise comparison matrix are scrutinized to verify the weights generated through the AHP approach. Once the key elements of suitability analysis within the AHP framework are established within a GIS platform, a final dumping site suitability map can be generated. Moreover, weighted overlay analysis is employed to combine multiple layers of data, and each layer is assigned weights based on a pair-wise comparison table. The revised formula incorporates calculations of the random index, consistency index, and λmax to guarantee a consistency ratio below 0.1, maintaining the reliability of the outcomes.

The Analytic Hierarchy Process (AHP) follows a well-defined process consisting of multiple steps: 1) The first step involves setting up a pairwise comparison matrix to determine the relative importance of each layer. This matrix includes the weights (w) assigned to each layer compared to other layers. It is crucial to ensure that the matrix satisfies the reciprocal condition, where the inverse of each entry is placed in the corresponding position. For example, if layer A is compared to layer B with a weight of 3, then layer B is compared to layer A with a weight of 1/3. 2)

The next step is to calculate the weighted normalized matrix (a). This is done by dividing each element of the pairwise comparison matrix by the sum of its corresponding column using the formula: $a_{ij} = w_{ij} / \Sigma(w_j)$. 3) After obtaining the weighted normalized matrix, the column sum vector (c) is calculated. This is done by summing up the elements of each column in the weighted normalized matrix: $c_i = \Sigma(a_{ij})$. 4) The weighted sum vector (w) is then calculated by multiplying the column sum vector (c) with the weights (w) assigned to each layer: $w_i = c_i * w_i$. 5) Next, the λmax (lambda max) value is calculated by summing up the elements of the weighted sum vector (w): $\lambda_{max} = \Sigma(w_i)$. 6) The random index (ri) is computed based on the size of the pairwise comparison matrix, using a predetermined table of values. 7) The consistency index (ci) is then calculated by subtracting the size of the matrix from the λmax value and dividing it by the size minus one: $ci = (\lambda_{max} - \text{matrix size}) / (\text{matrix size} - 1)$. 8).

The consistency ratio (cr) is determined by dividing the consistency index (ci) by the random index (ri): $cr = ci / ri$. 9) If the consistency ratio (cr) exceeds 0.1, the pairwise comparison matrix must be revised until the consistency ratio reaches an acceptable level. 10) Once the consistency ratio is below 0.1, the weighted sum vector (w) is used to generate the composite output. This is achieved by overlaying the layers using a suitable mathematical operation, such as weighted summation or boolean combination. By following these steps, the revised formula ensures that the weighted overlay analysis incorporates the random index, consistency index, and λmax calculations, effectively achieving a consistency ratio below 0.1. This guarantees more reliable and accurate results in the composite output.

To calculate the consistency index (ci), the eigenvalues of the matrix are required. In this case, the eigenvalues are $\lambda1 = 10.383$, $\lambda2 = 2.186$, $\lambda3 = 1.308$, $\lambda4 = 0.512$, $\lambda5 = 0.262$, $\lambda6 = 0.145$, $\lambda7 = 0.091$, $\lambda8 = 0.062$, $\lambda9 = 0.037$, and $\lambda10 = 0.017$. Using the formula $ci = (\lambda1 - n) / (n - 1)$, where n is the number of criteria, with n = 10, the consistency index (ci) is calculated as $ci = (10.383 - 10) / (10 - 1) = 0.383$. The random index (ri) is determined using a predefined table based on the size of the pairwise comparison matrix, which in this case is 10. The ri value is found to be 1.49. Finally, the consistency ratio (cr) is obtained by dividing the consistency index (ci) by the random index (ri): $cr = ci / ri = 0.383 / 1.49 = 0.257$. Ideally, the consistency ratio should be less than 0.1 for a reliable pairwise comparison. However, in this case, the cr is greater than 0.1, indicating that the pairwise comparison may not be completely reliable. Furthermore, the maximum eigenvalue (µmax) is calculated by summing up the eigenvalues and dividing it by the number of criteria: $\mu max = (\lambda1 + \lambda2 + \lambda3 + \lambda4 + \lambda5 + \lambda6 + \lambda7 + \lambda8 + \lambda9 + \lambda10) / 10 = (10.383 + 2.186 + 1.308 + 0.512 + 0.262 + 0.145 + 0.091 + 0.062 + 0.037 + 0.017) / 10 = 15.003 / 10 = 1.5003$. Therefore, the maximum eigenvalue (µmax) is 1.5003.

All of the parameters were weighted by their percentages. The pair-wise comparison matrix (PWCM), which evaluates the importance of the parameters regarding the geospatial analysis of disposal site selection on the basis of scale values ranging from 1 to 9, provides specific information about the relative importance of each relevant factor, as shown in Table 2. To increase the accuracy of the judgments to be made using the AHP approach, the consistency of the weights produced from the pair-wise matrix should be examined. The final dumping site suitability map of the study area was produced in accordance with the basic structure shown in Figure 12 after the key elements of suitability analysis in AHP were established in a GIS platform.

Table 2. Analytical hierarchy process scale and judgment.

Scale	Judgment
1	Equal importance
3	Moderate importance one over the other
5	Essential or strong importance
7	Very strong or demonstrated importance
9	The extreme or absolute importance
2,4,6&8	Intermediate values between the two adjacent judgments

Table 3: Pair-wise comparison matrix of the key factors.

	LULC	BA	Slope	Road	Lake	Stream	PA	Elevation	text	WFC
LULC	1	3	3	5	5	7	7	9	9	32
BA	0.333	1	3	3	3	5	5	7	9	20
Slope	0.333	0.333	1	3	3	5	5	7	7	16
Road	0.2	0.333	0.33	1	3	3	5	5	7	11
Lake	0.2	0.333	0.33	0.33	1	3	3	5	5	8
Drainage	0.143	0.2	0.2	0.33	0.33	1	3	3	5	5
PA	0.143	0.2	0.2	0.2	0.33	0.333	1	3	3	4
Elevation	0.111	0.111	0.14	0.2	0.2	0.333	0.33	1	3	2
ST	0.111	0.111	0.14	0.14	0.2	0.2	0.33	0.33	1	2

BA = Built -up area, PA = Protected area, ST = Soil texture, WFC = Weight for criteria

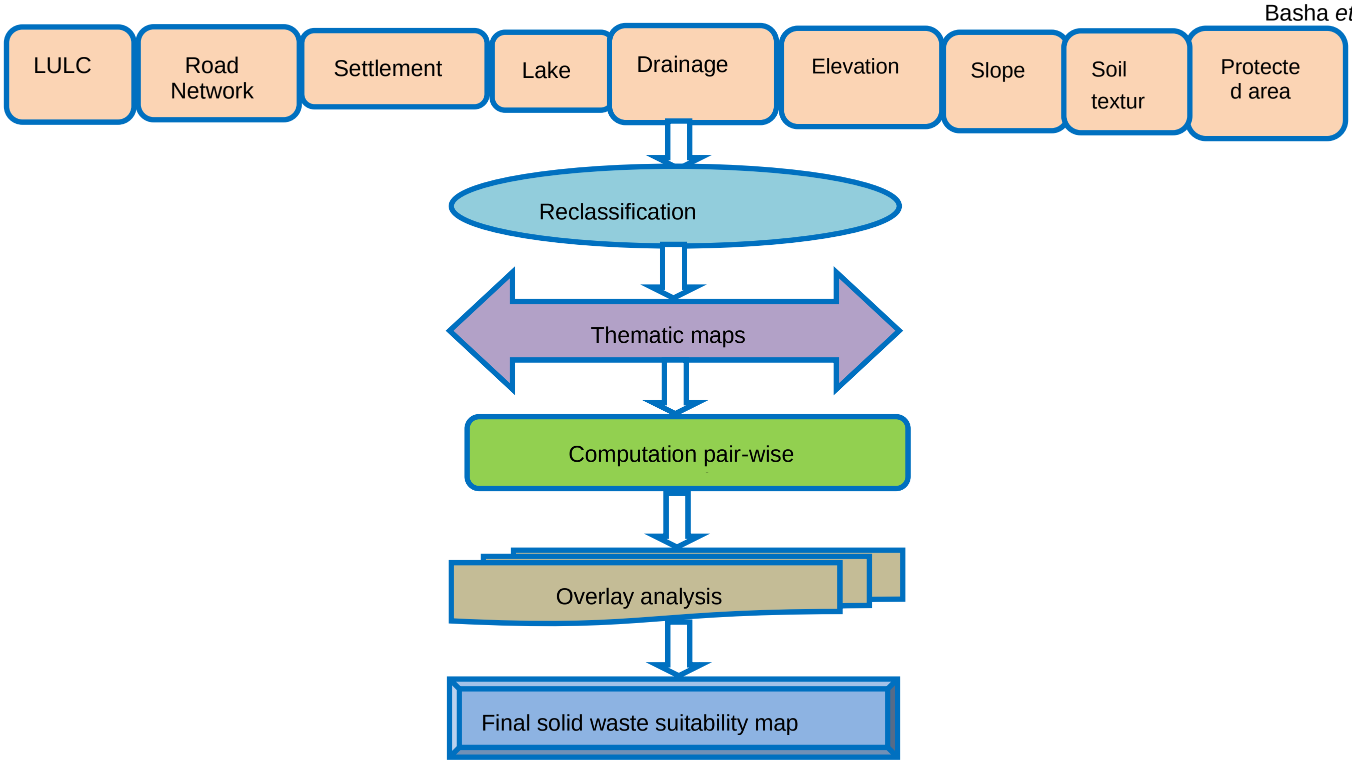

Figure 2: Geospatial and AHP flowchart for dumping sites suitability analysis.

RESULTS

Solid waste disposal site selection criterion

In order to avoid the subsequent negative long-term environmental and social consequences of solid waste, an optimum disposal placement strategy must go through a thorough process of criterion analysis. Based on standards, the significance and availability of data for the Haramaya disposal site in the areas, about nine disposal site criteria including LULC, road network, settlement, lake, drainage pattern, slope, elevation, soil texture, and protected area were taken into consideration when analyzing the suitability of a dumping site, and a suitability map was created for each criterion.

Suitability of Land use/land cover

Land use and land cover (LULC) is one of the crucial factors taken into consideration when choosing disposal locations. As a result, solid waste disposal cannot be practiced everywhere in the environment in which we live. Similar logic was followed throughout the suitability analysis: normally, the disposal site for solid waste shouldn't be positioned close to or in sensitive LULC zones like settlements, densely populated areas, agricultural fields, or water sources. In the current study, land uses that are suited for dumpsite selection are identified. It is essentially considered that these land uses are low-value and economically less valuable than the others.

Table 4: Area coverage and LULC suitability

No	LULC types	Suitability classes	Suitability rank	Area (ha)	Area(%)
1	Grass/bare land	Highly suitable	4	686	9
2	Forest	Suitable	3	123	2
3	Settlement/built up area	Moderately Suitable	2	1343	18
3	Cultivated land	Moderately suitable	2	4879	66
4	Swampy/flooded area	Unsuitable	1	84	1
5	Lake	Unsuitable	1	251	3

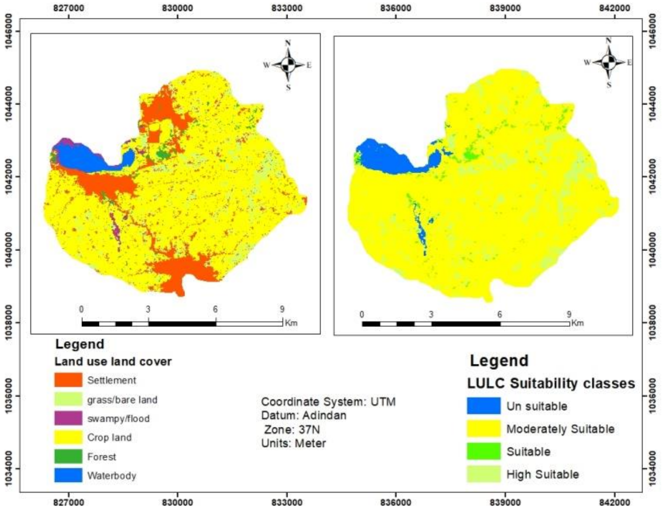

Figure 3: LULC types and suitability index

Suitability of settlement area

The presence of settlements is an important environmental factor when choosing a location for the disposal of solid waste. In this study, social services are provided in a variety of built-up locations, including residential (housing), institutional (religious, educational, and health), and commercial (supermarkets, shops, hotels, cafeterias, and marketplaces). These locations shouldn't be in close proximity to a solid waste disposal station. Haramaya towns and the university within the boundary of the study area are covered by these built-up areas, which are expanding at a fast rate due to urbanization. Locating dumpsites near settlement areas causes a slew of social and environmental issues. Placing dumpsites within cities, towns, or villages can result in pollutants associated with waste disposal, including litter, rodents, and unexpected disposal site fires. Disposal sites near settlements may lead to unattractive aesthetic conditions and create a bad smell, which may also expose urban inhabitants to health risks.

Table 5: Area coverage and Town buffer Suitability

No	Suitability classes	Suitability Rank	Buffer Distance (m)	Area(ha)	Area (%)	Reference
1	Highly suitable	4	3000-5000	700	10	(Bilgilioglu *et al*., 2022; Chabok *et al*., 2020)
2	Suitable	3	2000-3000	936	13	
3	Moderately suitable	2	1000-2000	1712	23	
5	Not Suitable	1	<1000	4006	54	

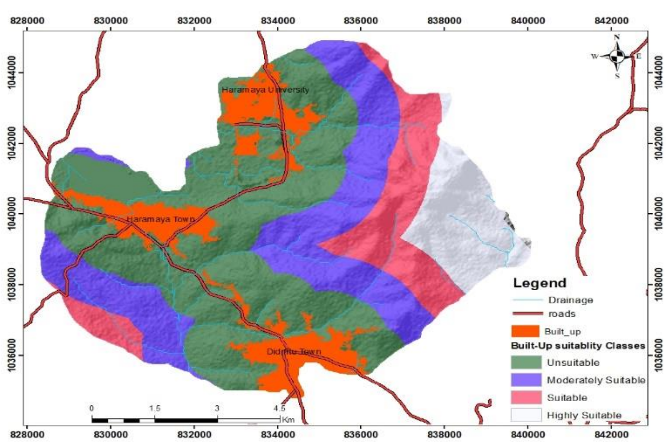

Figure 4: Settlement (built-up) suitability index

Suitability of road networks

The aesthetic condition of the natural landscape has a relevant impact on how well urban environments are planned and built.

The result of the road buffer analysis showed that 57% (4168 ha) of the total study area is unsuitable, whereas 5% (335 ha) is highly suitable for disposal site sitting. The remaining 13% (981 ha) are suitable, and 25% (1820 ha) are moderately suitable for locating disposal sites (Table 6). Thus, the closest distance from the road and more than half of the study area are not suitable for disposal site sitting, whereas a buffer zone covering 500–1500 m is a potential area that is highly suitable for disposal site sitting.

Table 6: Area Coverage and Road Network Suitability

No	Suitability classes	Suitability Rank	Buffer Distance in (m)	Area(ha)	Area (%)	References
1	Highly suitable	4	500-1000	335	5	(Ebistu & Minale, 2013)(Ayaim et al., 2019)(Rahimi et al., 2020)
2	Suitable	3	1000-1500	981	13	
3	Moderately suitable	2	1500-3000	1820	25	
4	Unsuitable	1	0-500	4168	57	

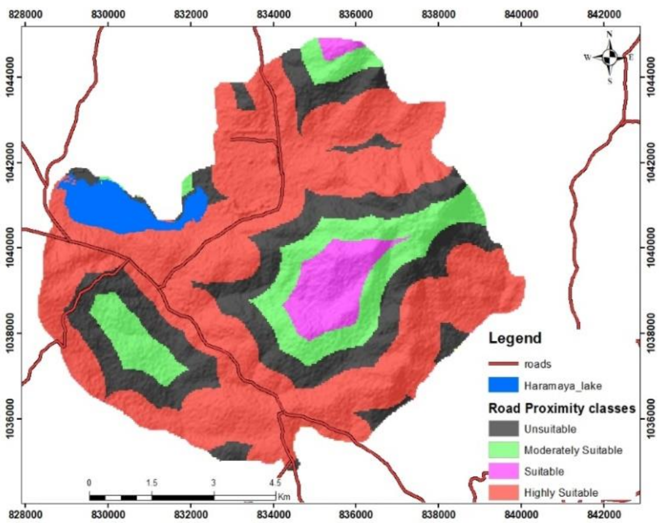

Figure 5: Road network suitability map

Suitability of water bodies

In this case, a buffer distance of less than 1000 m has been considered unsuitable for dumpsite placement, whereas a buffer distance of 1000-2500 m, 2500-4000 m, and 4000-5500 m have been considered to be moderately suitable, suitable, and highly suitable, respectively. About 13% (949 ha) of the total study area represents an exclusion zone, while 20% (1505 ha), 26% (1913 ha), and 41% (2999 ha) represent moderately suitable, suitable, and highly suitable zones, respectively.

Table 7: Suitability of area coverage and lake proximity

No	Suitability classes	Suitability rank	Buffer distance in (m)	Area(ha)	Area(%)	References
1	Highly suitable	4	4000-55000	2999	41	(Rahmat *et al*., 2017;(Ayaim *et al*., 2019); (Kamdar *et al*., 2019b)(Pasalari *et al*., 2018); Bilgilioglu *et al*., 2022)
2	Suitable	3	2500-4000	1913	26	
3	Moderately suitable	2	1000-2500	1505	20	
4	Unsuitable	1	0-1000	949	13	

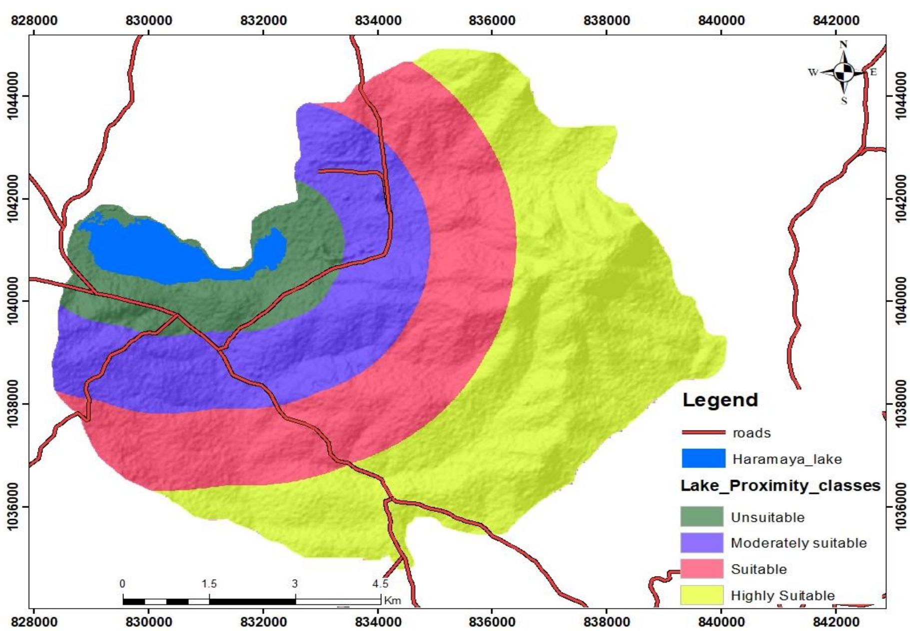

Figure 6: Lake Proximity suitability map

Table 8: Area coverage and drainage suitability

No	Suitability classes	Suitability rank	Buffer distance in (m)	Area(ha)	Area(%)	References
1	highly suitable	4	1000-2000	88	1	(Rahmat et al., 2017); (Khan & Samadder, 2014); (Alavi et al., 2013)
2	Suitable	3	500-1000	1661	23	
3	Moderately suitable	2	300-500	2005	27	
4	Unsuitable	1	0-300	3612	49	

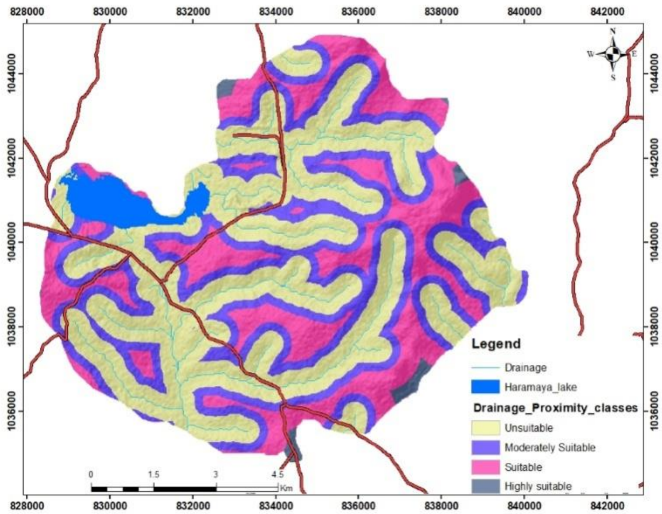

Figure 7: Drainage suitability map

Suitability of topography

Topographic conditions, such as the slope and altitude of the field, are among the most important factors to be considered when choosing a site for the disposal of solid waste. The slope influences ecological components such as soil's water content, the likelihood of erosion, surface runoff, and groundwater contamination. This is followed by acceptable, somewhat appropriate, and unfavorable areas, which account for 20% (2,807 ha), 38% (1,495 ha), and 40% (98 ha), respectively, of the total area. This suggests that slope is a crucial consideration for the disposal of SW

Table 9: Area coverage and slope suitability

No	Slope classes (%)	Suitability classes	Suitability Rank	Area(ha)	Area (%)	References
1	0-8	Highly suitable	4	2922	1	(Alavi *et al*., 2013; Ebistu & Minale, 2013;Effat & Hegazy, 2012; *Gorsevski et al*., 2012)
2	8-15	Suitable	3	2807	20	
3	15-30	Moderately suitable	2	1495	38	
4	>30	Unsuitable	1	98	40	

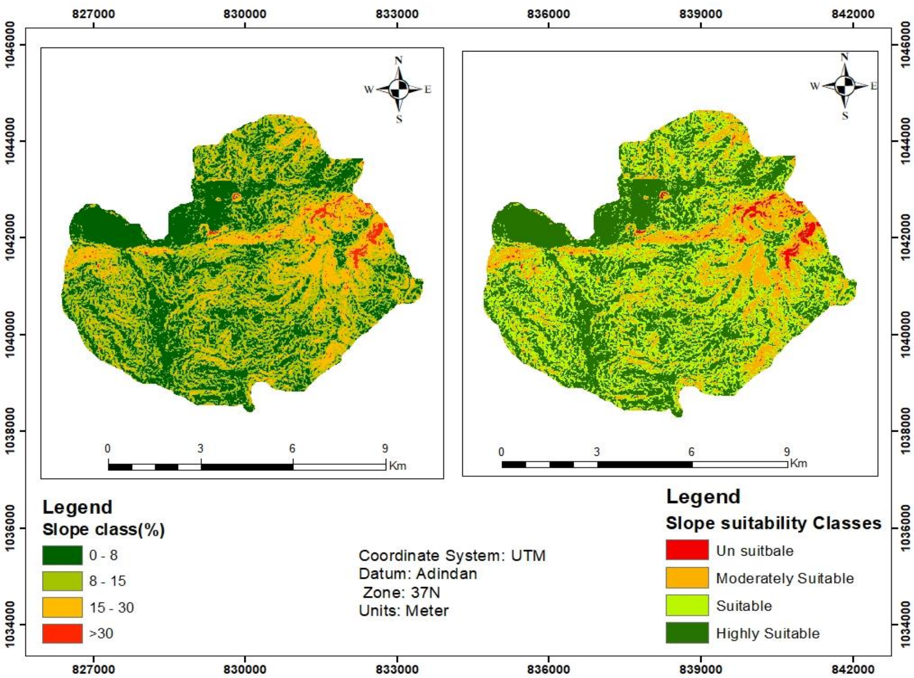

Figure 8: Slope classes and suitability map

Higher altitude areas, like slopes, are not appropriate for dumpsite areas. This is because the higher elevation makes access difficult, resulting in higher transportation costs and facilities, and because leachate easily moves from higher to lower areas.

Table 10: Area coverage and elevation suitability

No	Suitability classes	Suitability Rank	Buffer Distance in (m)	Area(ha)	Area(%)	References
1	Highly suitable	4	1,972 - 2,044	2502	34	(Majid & Mir, 2021), (*Asefa et al*., 2021b)
2	Suitable	3	2,044- 2,104	2732	37	
3	Moderately suitable	2	2,104 - 2,185	1570	21	
4	Unsuitable	1	2,185 - 2,303	563	8	

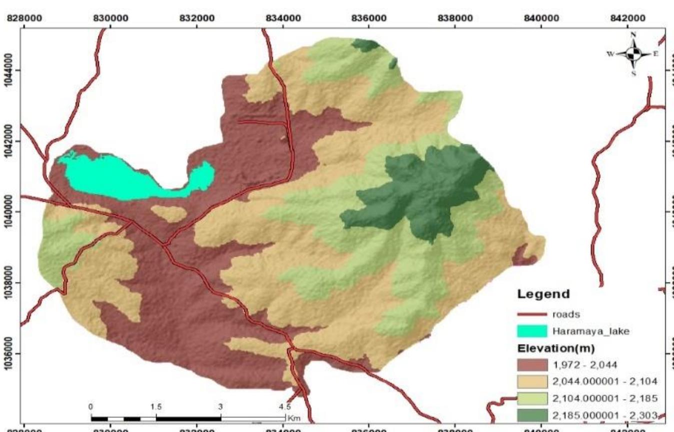

Figure 9: Elevation suitability index

Suitability of protected area

Socially valued areas, including universities, schools, jails, markets, health care facilities (hospitals, clinics), and worship sites (mosques and churches), shouldn't typically be located close to waste disposal sites.

Table 11: Area coverage and distance suitability

No	Suitability classes	Suitability Rank	Buffer Distance in (m)	Area(ha)	Area(%)	References
1	Highly suitable	4	3000-5000	801	11	(Effat & Hegazy, 2012)
2	Suitable	3	2000-3000	1795	24	(Ebistu & Minale, 2013)
3	Moderately suitable	2	1000-2000	2977	40	(Rahimi *et al*., 2020)
4	Unsuitable	1	0-1000	1794	24	(Pasalari *et al.*, 2019) (Chabok *et al*., 2020)

For the present study, SW dumping locations in the Haramaya area were divided into four categories: highly suitable (3000–5000 m), suitable (2000–3000 m), moderately suitable (1000–2000 m), and generally unsuitable (0–1000 m). According to the protected area suitability rating, only 11% (801 ha) and 24% (1795 ha) of the study area's landmass were classified as highly suitable and suitable, respectively. The remaining 40% (2978 ha) and 24% (1794 ha) of the total area were, respectively, moderately suitable and unsuitable. Due to the presence of Haramaya University, a town (Haramaya), and villages in the study area, as shown by both Table 11 and Figure 10, a very small area is generally highly ideal for choosing a waste disposal location.

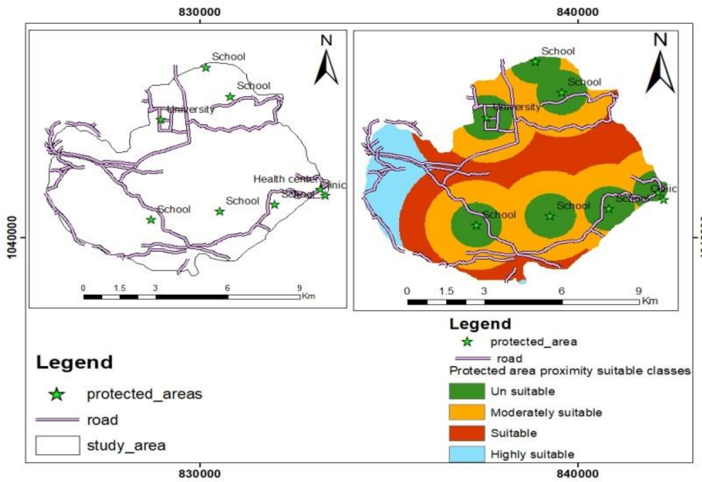

Figure 10: Protected area suitability map

Suitability of soil texture

The permeability of the textural unit is determined by several factors, including the soil when choosing a waste disposal site.

Table 12: Area coverage and soil texture suitability

No	Suitability classes	Suitability Rank	Buffer Distance in (m)	Area(ha)	Area(%)	References
1	highly suitable	4	Clay loam	5438	74	
2	Suitable	3	Silt clay loam	4	0.1	(Mohammed *et al*., 2019)
3	Moderately suitable	2	Silty	1579	21	
4	Unsuitable	1	Waterbody	346	4.9	

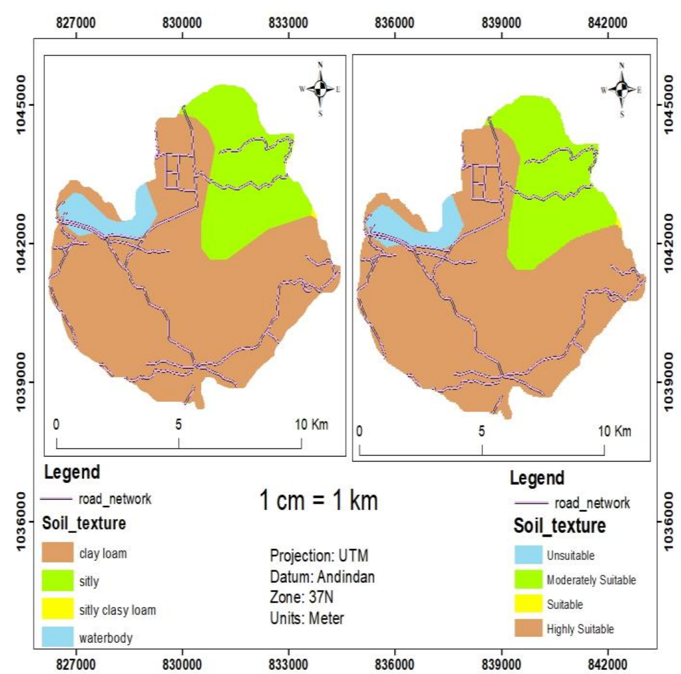

Figure 11: map of soil texture suitability classes

Suitability of final solid waste dumping zones

It is doubtful that the majority of sites will satisfy every requirement, in which case it would be impossible to determine if a site is suitable. Therefore, the optimum site with the least detrimental impact on the both people and the environment is required for the disposal facility. The location that has the least negative effects on environmental factors and satisfies the most site selection requirements is the most ideal for a SW disposal site. Using Arc GIS 10.1 software, different thematic layers and overlay analysis were done. According to the final suitability map analyses, the majority of the Haramaya area, 57% (4,170 ha), was moderately suitable for disposal among the other suitability classes. This was followed by unsuitable, which comprised 20% (1,464 ha). Out of the remaining area, 19% (1,353 ha) and 4% (296 ha) had suitable and high suitability classes, respectively (Table 13).

Table 13: Area coverage and suitability classes for solid waste disposal

No	Suitability classes	Suitability Rank	Area(ha)	Area (%)
1	highly suitable	4	296	4
2	Suitable	3	1353	19
3	Moderately suitable	2	4170	57
4	Unsuitable	1	1464	20

The delineated potential disposal site zones (suitable and high suitability) were found in three parts (the eastern, north-eastern, and south-western) of the selected Haramaya watershed, which were concentrated mainly in the eastern part**.** These potential sites were situated across moderately and highly suitable potential areas (Fig. 12 and Table 13).The LULC, proximity to a road, built-up area, lake, and slope conditions play an important role in the disposal site selection (32%, 20%, 16%, 11%, and 8%, respectively). This may be due to the high hypothetical weight of all of these factors (Table 3). However, the study areas northwest, south, and middle portions were identified as sporadically suited and banned locations for waste disposal sites. The majority of these locations were covered by Haramaya Lake and populated areas like towns and Haramaya University (Fig. 12).

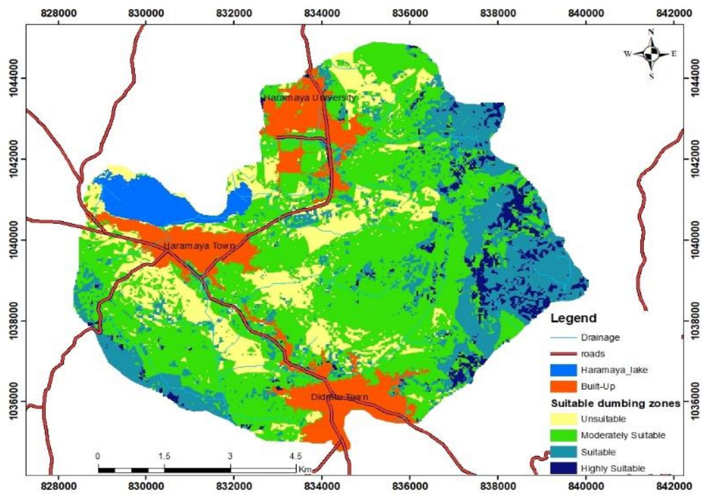

Figure 12: Final suitability map of waste disposal site

DISCCUSION

Land with less socioeconomic, ecological, and political value is proposed as a disposal place, according to studies (Yenenesh *et al*., 2019). The location of the dumping site is proposed to be open, barren terrain with grass or bushes (Ebistu & Minale, 2013; Tadese *et al*., 2022). The categorization used in the previous research served as the basis for the reclassification of the LULC suitability order used in this investigation (Ebistu & Minale, 2013). Considering this evidence, in this study, grass and barren ground are perceived to be more desirable for dumpsites compared to other land uses. The majority of the land was used for agriculture, making up approximately 66% (4879 ha) of the total area. Settlement (built-up) areas, grassy/bare land, lakes, forest land, and marshy areas followed, making up about 18% (1343 ha), 9% (686 ha), 3% (251 ha), and 2% (123 ha), respectively (Table 4 and Fig. 3). This result is nearly comparable to the finding of Kabite (2012).

Because the dumpsite is close to residential areas, rodents and disease-carrying vectors may be drawn to the garbage that has been dumped there, and air pollution from openly burning waste poses a threat to public health. According to Rahimi *et al.* (2020), building dumpsites in urban rural areas or villages is not advisable because of the detrimental effects it brings on inhabitants and property. As a result, disposal sites are not permitted within 1,000 m of settlement areas (Aneseyee & Sodango, 2022; Bilgilioglu *et al*., 2022; Kamdar *et al*., 2019b). Studies also showed that suitability has a linear increase from 1 to 5 km (from unsuitable to completely suiting) (Chabok *et al.*, 2020). The settlement area for this study was re-divided into four buffer distances based on Şener *et al*.

(2010) reports: unsuitable (1000 m), moderately suitable (1000–2000), suitable (2000–3000), and highly suitable (300–5000) for a solid waste disposal site (Table 4). Of the total area, almost 54% (4,006 ha) were inappropriate for a solid waste disposal location, while 23% (1712 ha) were only moderately appropriate. The remaining 13 percent (936 ha) and 10 percent (700 ha) are both appropriate and highly appropriate (Table 5 and Figure 4).

Due to the negative impacts dumpsites have on the public's health and the accompanying costs, they shouldn't be situated either too near or too far from existing road networks. As stated by Kebede *et al*. (2021) locating dumpsites too close to already-existing road networks puts people's health at risk, while placing them too far away wastes resources since it raises the cost of solid waste collection, transportation, and building new roads. A dumping site should be established, taking into account this problem at a reasonable distance from roadways to simplify transportation and hence lower relative costs. According to Ayaim *et al*. (2019; Ebistu & Minale (2013), buffer zones less than 500 m are undesirable for solid waste disposal sites, whereas those larger than 1000 m are the most appropriate. For this particular study, four overall road suitability distance intervals in meters were formed: highly suitable (500–1000), suitable (1000–1500), moderately suitable (1500–3000), and unsuitable (0–500), as shown in (Table 5).

Illegal SW disposal closer to surface water bodies has a significant impact on water quality in developing countries such as Ethiopia. According to a study conducted by Ahmad *et al*. (2013), the establishment of dumpsites nearer to water bodies such as rivers, lakes, streams, and ponds is prohibited in areas where there is a risk of groundwater or surface water pollution. The distance between a dumpsite and surface water bodies, such as lakes, and site selection (Town *et al*., 2019). This could be a result of the fact that it minimizes surface, subsurface, and groundwater contamination in water bodies. Solid wastes are dumped close to and in the river, which pollutes the water and lowers its quality, causing ecological issues that have a long-term effect on people and animals that utilize the river for diverse purposes. Several studies have shown that a minimum distance from any surface water must be at least 1 km (Al-Jarrah & Abu-Qdais, 2006; Effat & Hegazy, 2012; Pasalari *et al*., 2019). Similarly, a 1000 m protective barrier was created around the lake to safeguard surface water resources, and this area was excluded from the solid waste disposal zone (Bilgilioglu *et al*., 2022). Because of this, dumpsite should be placed far away from surface water bodies in an optimum location. As indicated in Fig. 6 and Table 7, the area was split into four categories of lake proximity suitable for this particular study. Alavi *et al*. (2013); Khan & Samadder (2014); Rahmat *et al*. (2017) also stated that dumpsites should never be located within a distance below 300 m and that at least 300 m is a minimum buffer distance for waste disposal sites. Similar studies conducted by Ayaim *et al*. (2019); Kamdar *et al*. (2019a) also show that buffer zones shorter than 300 m are inappropriate. Based on the criteria for buffer zones used for surface water in water bodies including rivers, streams, lakes, marshes, etc., the research area was categorized into four groups (Kabite, 2012).

Based on the findings from Table 8 and Figure 7 in this research, it was observed that approximately 49% (3612 ha) of the total area was deemed unsuitable for drainage with a buffer distance of 0-300 m. In contrast, 27% (2005 ha) of the land and 23% (1661 ha) of the area were considered moderately suitable, with buffer lengths ranging from 300-500 m and 500-1000 m respectively. Lastly, a small portion accounting for 1% (88 ha) of the entire land, utilizing a buffer distance of 1000-2000 m, was deemed highly suitable. These findings appear to align quite closely with previous studies conducted by Ayal (2020); Kenate (2017). To protect surface water from pollution, a minimum distance of 300 m from surface water drainage (rivers and their tributaries) was utilized in the current study's results. Therefore, as the distance between the dumping site and water bodies increases, the likelihood of water pollution decreases. According to (Rahmat *et al.*, 2017), the slope is important for dumpsite development since a greater slope results in higher construction costs. This is because a substantial budget is required, as well as a large number of workers, technology, and materials. Akbari et al. (2008) reported that areas with high altitudes or steep slopes are not suitable dumpsites. As a result, the dumpsite should be constructed on lower slopes, ideally less than 15%. Steep areas with improper slopes should be avoided when selecting disposal sites. Elevated plains or areas with gentle slopes are the preferred locations for dump sites. Steep slope areas have limited suitability for disposal sites due to the increased risk of hazardous and destructive events brought on by heavy rainfall and water infiltration (Motlagh & Sayadi, 2015). The slope between 0 and 6 degrees (0–10.5%) is the most ideal, while more than 15 degrees (268%) is the worst (26.8%) (Effat & Hegazy, 2012). Plain areas between 0 and 10% are the most appropriate, and the slope suitability is declining from best to worst, which is 10 to 40% (Wang *et al*., 2009).

Similarly, the places for elevated locations with less than 10% are the most appropriate for dumpsite site selection (Alavi *et al*., 2013; Ebistu & Minale, 2013; Gorsevski *et al*., 2012). Also, Adeli & Khorshiddoust (2011) revealed that the appropriate site for urban SW disposal must be located in a flat area with a gentle slope of 30° (8.33%). For these issues, the slope of the present study area was developed from DEM data at 30 x 30 m resolution and used in a GIS environment. For this study, the slope was divided into four main categories: highly suitable (0–8%), suitable (8–15%), moderately suitable (15–30%), and unsuitable (>30%), as indicated in Table 6 and Figure 8. The range of slopes indicated by the studies served as the basis for the reclassification of the slope that was used in this study. According to Table 9, which represents 1% (2922 ha) of the research area's total area, the study area's slope is dominated by a highly appropriate slope.

The possibility of a slope failure beneath or beside the dumpsite, which is located at a higher altitude, is also possible (Majid & Mir, 2021). As a result, an area's appropriate disposal site declines as its altitude rises. Additionally, studies on elevation suitability have also been conducted (Asefa *et al*., 2021a). Classified elevation ranges between 2033-2158 m as inappropriate, 1962–2032 m as least appropriate, 1790–1822 m as appropriate, and 1680-1889 m as highly appropriate. (Majid & Mir, 2021) classified elevation ranges between 2032-2158 m as inappropriate, 2032–2083 m as least appropriate, 1790–1822 m as appropriate, and 1680 m as highly appropriate and also identified elevations above 1800 m and between 1701-1800 m as unsuitable ranges, and between 1601-1700 m and below 1600 m as potential ranges for solid disposal locations. As a result, the study area is divided into four parts according to altitude, with the altitudes above mean sea level (MSL) between 2185-2303 m as highly suitable, 2104-2185 m as suitable, 2044 - 2104 m as moderately suitable, and 1972-2044 m as unsuitable (Fig. 9 and Table 10). This finding also indicated that a large portion of the study area had a lower altitude range, which is a potential zone (both highly suitable and suitable) for siting dumpsites, covering 34% (2502 ha) and 37% (2732 ha), respectively. In contrast, a small portion, 8% (563 ha), of the area has a higher altitude range, which was excluded from the disposal site zone. For the dumpsite, the remaining 21% (1570) was rated moderately appropriate.

The appropriateness of protected areas has garnered significant attention in numerous studies. Notably, a distance of less than 1 km from a protected area is deemed undesirable for dumpsites, as established by Ebistu & Minale (2013); Effat & Hegazy (2012). On the contrary, a distance exceeding 7 km is considered optimal, as asserted by Rahimi *et al*.(2020); Pasalari *et al*.(2019) found that the suitability of protected areas increases progressively from 1 to 6 km, transitioning from unsuitable to entirely suited. Concurrently, the buffer distance between protected areas and sensitive zones progressively expands from 1 to 5 km, as examined by Chabok *et al*.(2020); Motlagh & Sayadi (2015). In relation to dumpsite selection, Mohammed *et al*. (2019) discovered that the site appropriateness for digging and susceptibility to leachate intrusion decreases as the permeability of the textured unit increases. This finding highlights the potential for leachate contamination in nearby groundwater and surface water. Examining the study area's soil textures and types, three main soil classes were identified. Notably, clay loam soil class predominates, covering a significant area of 74.4% (5438 ha), rendering it highly suitable for disposal site sitting. Conversely, water bodies encompass 4.9% (346 ha), rendering such areas completely unsuitable. The remaining area presents a mix of silt clay loam and silt soils, encompassing 0.1% (4 ha) and 21% (1579 ha), respectively, with varying levels of suitability (Table 12 and Fig. 11).

CONCLUSION

Solid waste management is a growing concern in urban areas of developing countries like Ethiopia and the study highlights the importance of scientific disposal site selection in managing solid waste in urban areas. By using GIS and AHP methods, the study identified three suitable and scientifically selected disposal sites in the eastern, north eastern, and south western parts of Haramaya, while the northwest, south, and central parts were found to be unsuitable for waste disposal. Therefore, the finding emphasizes the need for relevant authorities to follow and consider the identified areas for effective waste management.

SUGGESTION

Based on the above results, the authors suggest that local government officials, specialists, and urban planners make a great effort to promote sustainable development in the study area. The present solid waste disposal facilities in the study area are not compliant with environmental rules, and the municipalities there must build a new site in identified appropriate places, and take care of excluded and rarely suitable areas for use as a dump site.

AVAILABILITY OF DATA AND MATERIAL

The corresponding author can provide the raw data that was gathered and used to support the study's conclusions upon reasonable request.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ETHICAL APPROVAL

This study does not involve any human or animal testing.

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AUTHOR'S CONTRIBUTION

Basha Gedefa: prepared the title, collected data, and wrote the manuscript. Gelana Fikadu: designed, analyzed and interpreted and wrote the manuscript. Gamtesa Olika: prepared all maps, and wrote manuscript and edited.

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