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Abstract

Rapid urbanization in developing countries has intensified the issues of solid waste management, raising serious environmental and public health concerns. This study was proposed *to* assess the suitability of waste disposal site locations and the environmental effects in the expanding satellite city of Muhanga, Rwanda. The main objective was to assess waste disposal site location that is environmentally friendly, economically feasible and socially acceptable in the satellite city of Muhanga. To achieve the objective, the research has employed a mixed-methods approach, combining Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) methodologies. GIS was used to examine spatial data on environmental, socioeconomic, and infrastructure issues to determine the feasibility of current and potential garbage disposal locations. AHP was applied to prioritize and rank site selection criteria, ensuring a systematic and data-driven evaluation process. The findings show that Muhanga's present waste disposal sites are improperly situated, with some in environmentally sensitive locations such as wetlands and near water sources, causing soil, water, and air pollution issues. The GIS-AHP study revealed ideal sites that fulfill environmental, social, and economic objectives while minimizing negative consequences. The final suitability analysis found that no place in the research matched all the requirements for a highly acceptable solid waste disposal site, highlighting the importance of rigorous environmental and social protections. The analysis determined that 1.7% (175 ha) of the study area was appropriate, with 31.1% (3,217 ha) being moderately suitable. The bulk, 66.9% (6,922 hectares), was deemed least acceptable, with just 0.3% considered entirely unsuitable. Site selection was heavily influenced by proximity to built-up areas, roads networks, rivers, wetlands, and topographical limits such as slope. The suitable areas were found in the West-South, North-West, and South-East parts of Muhanga's satellite city, especially in grassland regions away from heavily inhabited areas and water bodies. The study concluded that the poor waste disposal practices in Muhanga satellite city leads to environmental deterioration and public health risks. It recommends a comprehensive waste management approach that includes better site selection, improved waste collection, and enhanced recycling and treatment initiatives. It also emphasizes the need for improved district planning and regulatory enforcement to promote sustainable waste management throughout the satellite city's urban expansion.

Keyword*: Rapid Urbanization, Solid Waste Disposal, Waste Management, Suitability Analysis, GIS, Analytical Hierarchy Process*

1. Introduction

Solid waste production has dramatically increased due to global industrialization and urbanization, posing major environmental and socioeconomic concerns. The World Bank estimated that municipal solid waste generation reached 2.1 billion tons in 2016 and will rise to 3.4 billion tons by 2050 (Kaza et al., 2020). However, about 33% of this waste is not managed safely (Kaza et al., 2020). Improper disposal leads to land, water, and air pollution, threatens human health, reduces biodiversity, and lowers living standards (World Health Organization, 2024). Waste collection rates show major disparities: developed countries achieve 96%, while least-developed countries manage only 39%, and low-middle-income countries 51% (Kaza et al., 2018). Globally, 2 billion people lack waste collection services, and waste from 3 billion is improperly disposed of or burned (Kabera et al., 2019).

Sub-Saharan Africa faces growing waste management challenges as urbanization accelerates. Waste generation is expected to increase from 178 million tons in 2016 to 269 million tons by 2030, while collection rates remain low at around 44% as of 2018 (Adedara et al., 2023). Poor infrastructure limited political will, weak policies, financial constraints, and low public awareness impede progress (Diaz et al., 2017). The UNEP projects that the urban population in Sub-Saharan Africa will double by 2050, further complicating waste management systems (Citaristi, 2022). Practices such as open dumping and uncontrolled burning continue to harm public health and ecosystems (Keza et al., 2018; Kumar et al., 2022). Sustainable solutions must be tailored to the region's specific conditions (Kabera et al., 2019; D. Wilson, 2015).

In Rwanda, rapid urbanization and migration to cities have increased the complexity of waste management (Victoire et al., 2020). Rwanda's population is projected to grow from 13.6 million in 2023 to 23.6 million by 2050, with urbanization reaching 70% (NIRS, 2022). As waste volumes rise, infrastructure development must keep pace. Currently, Rwanda produces approximately 1.5 million tons of solid waste annually, with about 40% collected and recycled (GIZ, 2023). Nevertheless, access to formal waste collection is limited, with only 42.1% of urban and 0.2% of rural households covered (NISR, 2020).

Muhanga city, located southeast of Muhanga District and one of Kigali's satellite cities, reflects these national trends. Rapid population growth, infrastructure expansion, and economic activities have increased pressure on waste management systems (Rutayisire et al., 2019). Facilities for collection, transport, treatment, and disposal are struggling to match rising demand (Muheirwe et al., 2022). Mismanagement could result in severe health risks, environmental degradation, and loss of biodiversity (Rutayisire et al., 2019). Effective waste management is essential for sustainable urban growth, but it demands integrated and resource-intensive strategies (World Bank, 2020; Muheirwe et al., 2022; Ndizeye et al., 2021).

The Global Green Growth Institute (2019) estimated that Muhanga produced around 50 tons of waste daily, with a per capita generation of 0.6 kg/day. By 2022, the city's population had grown to 87,252 residents, suggesting a waste production increase to about 52.35 tons daily (NISR, 2022). As urbanization continues, evaluating waste disposal practices becomes urgent.

Poorly located disposal sites can contaminate land, water, and air, threatening human and ecological health (Ampofo et al., 2023; Jibril et al., 2017). Proper site selection protects the environment and supports sustainable development (Semernya et al., 2017; Brohi et al., 2023). Therefore, this study aims to assess the suitability and environmental effects of waste disposal sites in Muhanga city, Rwanda.

1.2 Objectives of the Research

1.3 General Objective

The general objective of this research was to assess the solid waste disposal system and produce GIS-based maps for suitable location of solid waste disposal sites, while considering key locations factors, environmental effects, sustainability in the rapidly growing satellite city of Muhanga, Southern Province, Rwanda

1.4 Specific objectives

(i) To assess the solid waste disposal system in the satellite city of Muhanga,
(ii) To identify the key factors and criteria influencing appropriates waste disposal location,
(iii) To analyze the environmental effects of solid waste disposal and the potential risks associated with the site selection in the satellite city of Muhanga,
(iv) To produce a GIS-based suitability maps for suitable locations for solid waste disposal sites in the satellite city of Muhanga.

2. Materials and methods

2.1 Geographical location of Muhanga satellite city

Muhanga Satellite City, located in Rwanda's Southern Province about 50 km southwest of Kigali, sits at 2°05′04″S latitude and 29°45′10″E longitude, with an elevation of 1,621 meters. Encompassing 76 square kilometers, it includes Nyamabuye sector and parts of Shyogwe, Cyaza, and Muhanga sectors. Designated under the 2021–2050 National Land Use District Management Plan (NLUDMPs) as a smart, green satellite city supporting Kigali, Muhanga is envisioned as a future hub for mining, logistics, and trade. Geographically central, it benefits from major road networks linking other cities, enhancing its potential for urban expansion.

Muhanga experiences a tropical climate with two rainy and two dry seasons. Temperatures range from 10°C to 30°C, with annual rainfall between 700–1400 mm, peaking in April. Topographically, it is hilly, with slopes mostly between 0–8%. Population growth is steady, projected to rise from 50,608 in 2012 to 730,578 by 2050, alongside a substantial increase in households. Economic activities are dominated by trade, public administration, transport, and services, with restaurants, hotels, and trading centers being especially prominent.

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Volume 9||Issue 2||Page 126-168 ||April||2025|
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Muhanga plays a vital role as a logistics and trade hub, facilitating goods redistribution between Kigali and other regions. The city is experiencing rapid real estate development, particularly in newly emerging residential areas.

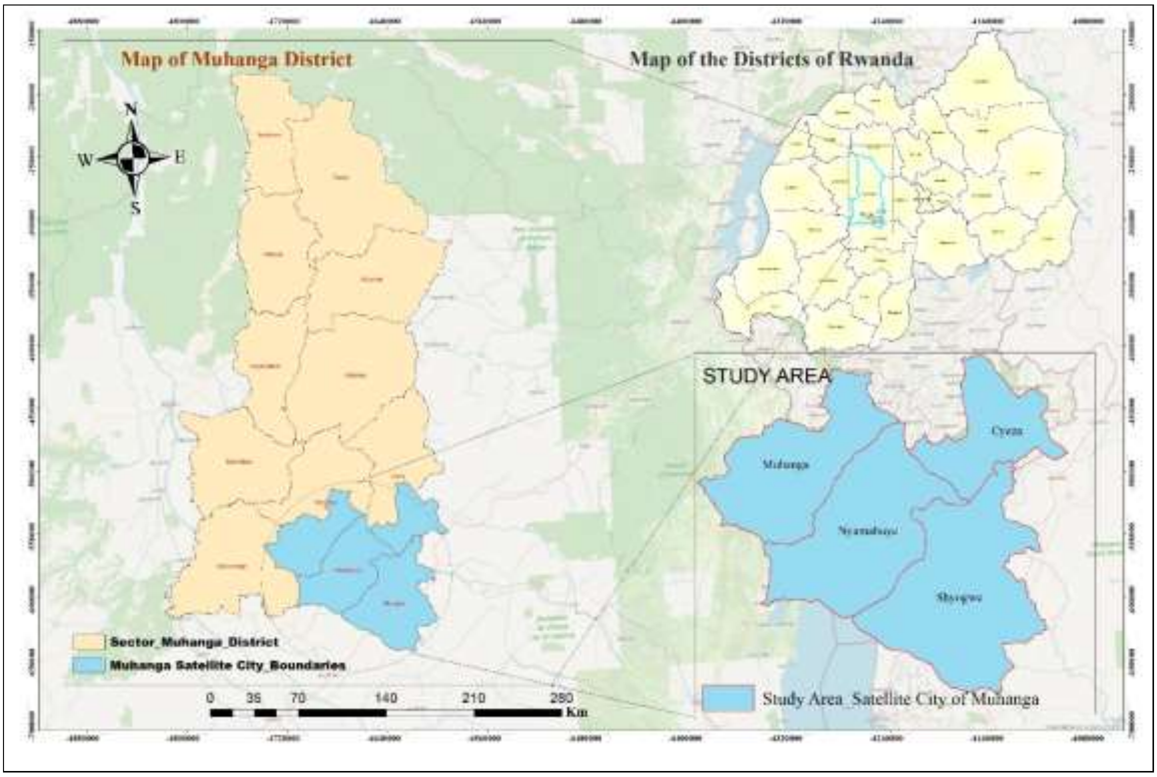

Figure 0:1. Location map of the study area, Muhanga city (author, 2024)

2.2 Research design and data collection methods

This study adopted a mixed-methods approach to assess the feasibility and environmental impacts of waste disposal sites in the satellite city of Muhanga, Rwanda. Quantitative analysis utilized Geographic Information Systems (GIS) to systematically collect and analyze spatial data such as topography, land use, surface water, and infrastructure. Qualitative analysis applied the Analytical Hierarchy Process (AHP) to prioritize and weight environmental, technological, and socioeconomic factors influencing site selection. AHP involved constructing pairwise comparison matrices and using a 9-point scale for decision-making, incorporating stakeholder input. A weighted overlay analysis was conducted to integrate multiple criteria and generate a suitability map categorizing areas into highly suitable, suitable, and unsuitable zones. Hardware included PCs, GPS receivers, and digital cameras, while software tools such as ArcGIS 10.8, MS Word 2016, and MS Excel 2016 supported data processing, analysis, and reporting. Strict data validity and quality control measures ensured reliability, sourcing information from reputable organizations like the National Institute of Statistics of Rwanda. Challenges like data variability and resource constraints were addressed through collaboration with local entities and the use of ICTs, including remote sensing and GIS.

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Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 126-168 ||April||2025|
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2.3 Illustration of research methodology

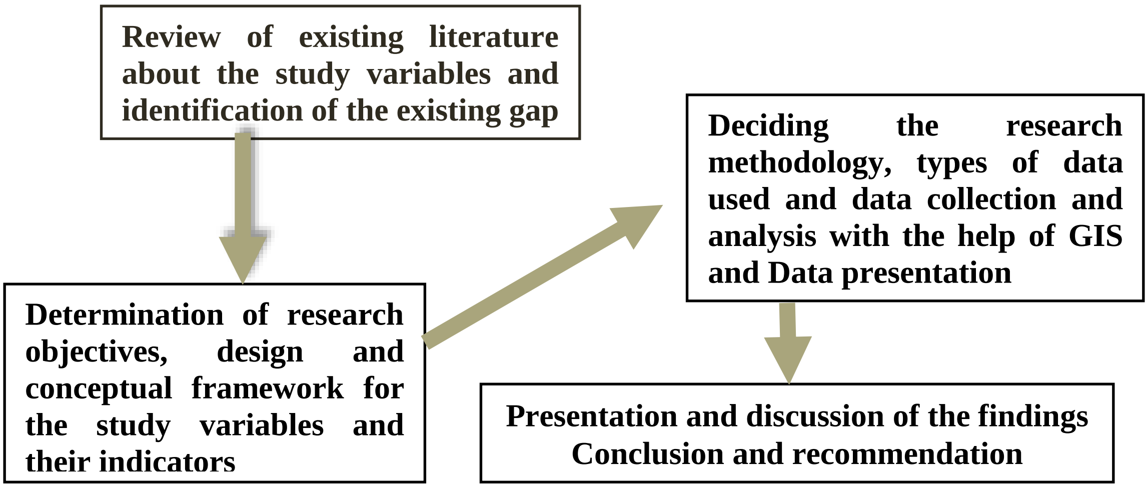

Figure 2.1: Methodology flowchart followed by the researcher

3. Results

3.1 Findings on solid waste management in the satellite city of Muhanga

3.1.1 Current waste disposal practices in the satellite city of Muhanga

The study found that waste management systems in the satellite city of Muhanga has several challenges, including inadequate infrastructure, poor waste segregation, illegal dumping, low public awareness, and limited funding. Waste collection and disposal facilities are insufficient, and a lack of separation at the source results in poor recycling. Some places experience illegal solid waste disposal sites due to inadequate facilities, while public awareness of appropriate waste disposal remains low. Furthermore, low financing impedes the improvement of waste management services and infrastructure. Regarding the management of solid waste produced in the satellite city, the administration of Muhanga district has contracted a private company, AGRUNI. LTD., for collection and transportation of solid waste generated throughout the satellite city of Muhanga. Contractors collect solid waste weekly from homes and other places such as restaurants, schools, offices, hotels, public spaces, and industrial zones.

The contractor makes a daily waste collection plan for each specific collection block, and the contractor's workers go door-to-door, as well as shops, and other public institutions collecting waste and place it along the road where the collection vehicle can pick it up and transport it to the final disposal site. However, due to the large coverage area managed by a single company, the collection may take up to a month to return to initial collection point the first place. Accordingly, residents and others institutions used to collect and keep the solid waste into sacs and other containers, and when it's their scheduled time for waste collection, company workers pass through homes and other places to move the filled sacs to the roadsides where the collection vehicle later arrives to empty the sacs for transporting the collected waste to dumping site (Researcher's survey, 2024).

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Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 126-168 ||April||2025|
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The 2019 report of Global Green Growth Institute (GGGI, 2019) indicate that solid waste generated in the satellite city of Muhanga is predominately organic, accounting for approximately 64%. The remaining 36% consists of paper (2%), plastics (2%), metals (1%), textiles (1%), electronic waste (1%) and healthcare waste (1%) and other materials (28%). The findings of National Institute of statistics of Rwanda (NISR, 2022) pointed out different solid waste disposal practices in the satellite city of Munga. Its findings show that only 13% of solid waste produced is collected by the contracted company and disposed of at legally dumping sites. Meanwhile, 37.5% of solid waste is thrown in bushes and household' field, and 43% is disposed of in household compost dumps.

3.1.2 Legal and illegal solid waste disposal sites.

Solid waste in Muhanga is now disposed of in both legal and illegal locations. The Figure 3.2 presents the identified location of existing legal and illegal dumping site in Muhanga satellite city. The study revealed that, while some allowed disposal locations exist, additional illegal garbage dumping spots have formed, particularly near riverbanks, roadsides, and open fields. Although district's officials supervise regulated location, unauthorized waste dumping remains a problem due to poor monitoring and enforcement procedures. The lack of sufficient infrastructure in certain legal places exacerbates environmental deterioration.

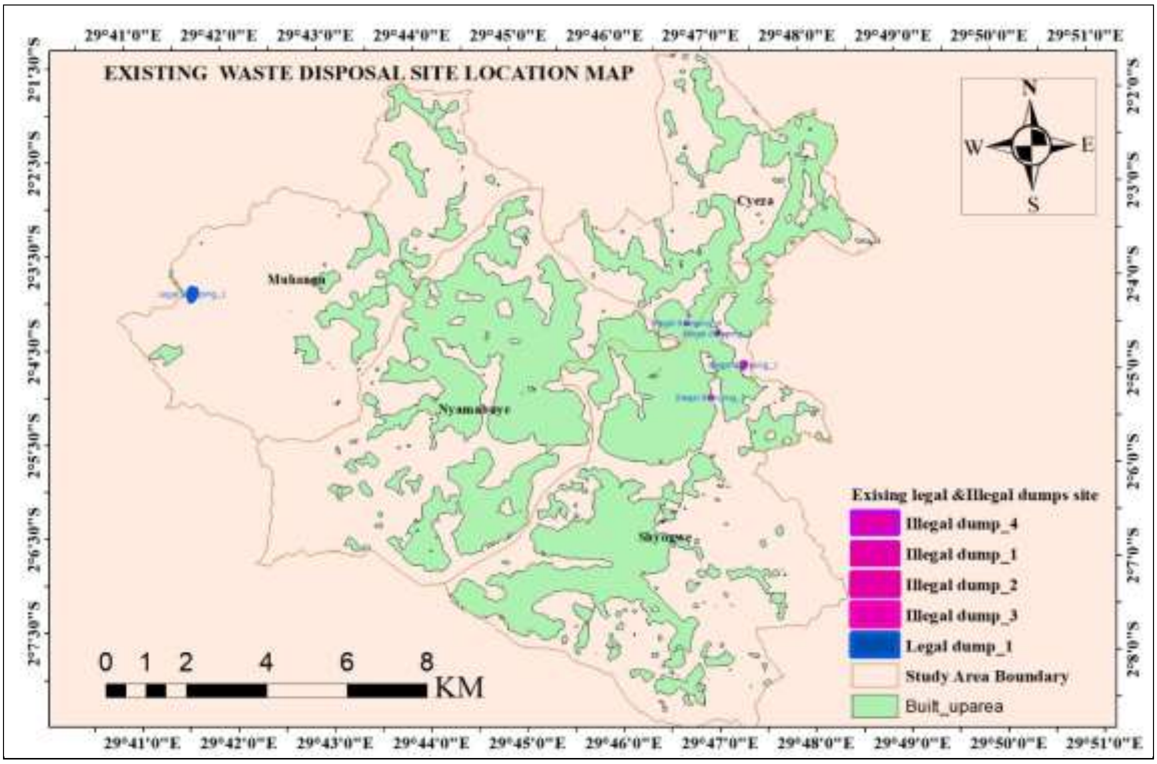

Figure 0:1 Existing dumping sites locations in Muhanga Satellite city

Researcher' survey, 2024

The map 3.1 shown both legal and illegal dumping sites surveyed in this study. The study found that that authorities of Muhanga district have designated a single open dumping site, situated 12 kilometers from Muhanga city center where it is located in Kanyinya village, Nyarusange sector, nevertheless, their decision was focused on distance from the city center. Despite the distance, the current waste disposal system is not satisfactory, based on the observation and interview, because it doesn't take account for the health risks issues such as agricultural field and settlement; additionally; there are deepened waterways that pass closer to the disposal, and this transport the liquid waste into nearly river. The residents living near the existing open dumping site experience significant air pollution, particularly during rain seasons. The sites also serves as a food source and foraging area for various animal species, including terrestrial wildlife such as birds, rodents and reptiles, as well as domestic livestock like pigs, goats, sheep, and chickens. Additionally, other dumping sites identified in the study area are used illegally. Both figures 3.2 (A) of legal and 3.3 (B) illegal dumping sites highlight inadequate solid waste management practices in satellite city of Muhanga.

A) **Legal open dumpsite for solid waste disposal at the study area**

Figure 0:2 Legal waste disposal site at Kanyinya along (1) near the agricultural fields, (2) nearby settlement area- village of Kanyanya, (3) feeding domestic livestock, and (4) above the water drain system (Field survey 2024)

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Volume 9||Issue 2||Page 126-168 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

B) Illegal open dumpsites for waste disposal in the study area

Figure 3.3 Illegal waste disposal sites along (a) drainage, (b) in forest and (c) public compost

Field survey 2024

Field survey conducted by traversal walk means revealed that some the solid waste generated in the satellite city of Muhanga is illegally dumped in on pen space, such as drainages, forests, and public composts. The solid waste disposal system can actively engage all stakeholders to directly reduce solid waste generation, maintain clean streets, ensure appropriate preparation and storage for collection, and enable more cost-effective operations (Abubakar et al., 2022). Households should use multiple containers to ensure the separation of biodegradable and non-biodegradable solid waste for proper final disposal.

What is presented in figures 3.3 illustrate that the administration of Muhanga district did not satisfactorily in waste management, particularly in involving community, developing a proper plans, and providing temporary waste containers. These containers could be placed in designated locations for contractors to come later and collect. This may facilitates waste disposal for community members who don't afford to pay for home waste collection services. It is evident that waste collection contractors put in significant efforts to keep the city clean and the district administration fulfill its duties to make plan annually. However, one may argue that the district has not succeeded to implement waste disposal sites that are environmentally sound, economically feasible and socially acceptance for waste disposal. The findings show that, while Muhanga has some waste management infrastructure in place, numerous gaps persist. Addressing concerns such as illegal dumping, infrastructural restrictions, and environmental monitoring are crucial for sustainable waste management in the future. Furthermore, the development of additional waste disposal facilities and increased regulatory enforcement are important moves ahead.

3.2 Selection of key factors for assessing waste disposal suitability

The criteria selection and analysis for assessing suitable location of waste disposal sites in the satellite city of Muhanga directly align with the second objective of this study. The criteria selected were then assessed based on the frequency of selection among the 12

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Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 126-168 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

participants, which was expressed in terms of percentage and approximate number of experts. The analysis of responses indicated that respondents highlighted 9 main criteria to varied degrees of emphasis. The results are given in descending order of priority based on the proportion of experts who picked each criterion as presented in figure 3.4 .

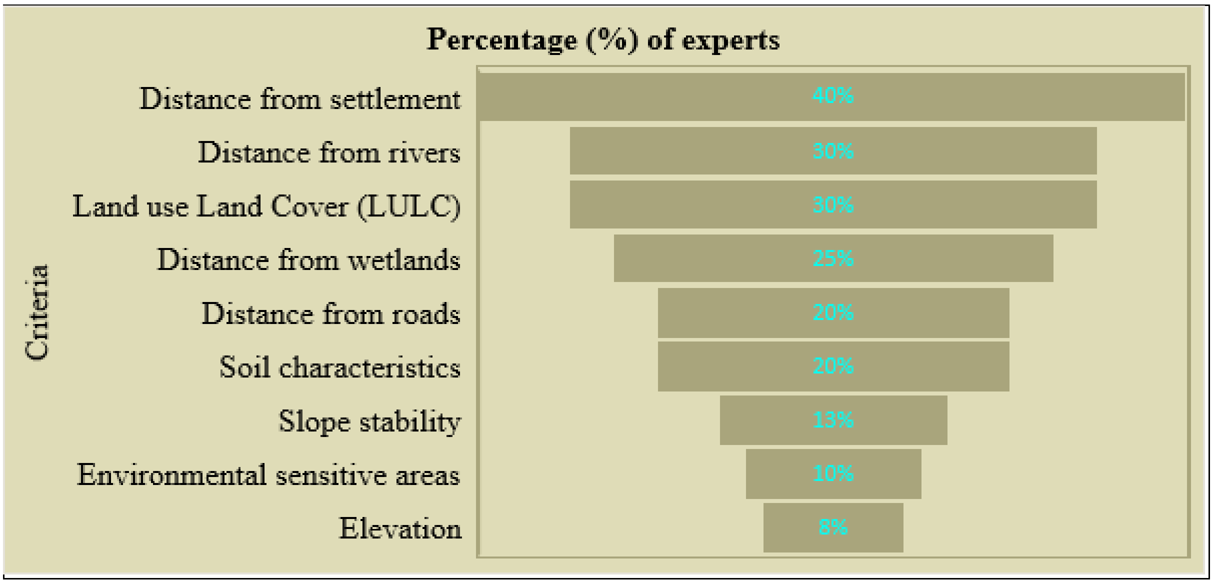

Figure 3:4 Criteria selection results by Interviewees' participants

The expert assessment revealed that Distance from Settlement was the most frequently cited criterion, with 40% of participants emphasizing its importance in minimizing public health risks and nuisance. This was followed by Land Use/Land Cover (LULC) and Distance from Rivers, each selected by around 30% of experts, highlighting concerns over land zoning regulations and potential water contamination.

Distance from Wetlands was prioritized by 25%, reflecting the ecological sensitivity of these areas. Distance from Roads and Soil Characteristics each received 20%, indicating moderate concern for site accessibility and soil suitability in controlling leachate and structural stability. Slope stability was evaluated by 13%, while Environmental Sensitive Areas were recognized by 10%, indicating a lesser but still considerable concern for terrain integrity and ecosystem conservation among experts. Elevation was the least priority criterion, observed by just 8%, indicating that is a very small role unless influenced by site-specific topography.

Following expert's input, the second step included translating these criteria into quantifiable spatial dimensions. Based on current literature and context-specific knowledge, each criteria was classed into five appropriateness categories, ranging from Unsuitable (1) to Highly Suitable (5). As a result, the data in table 3.1 indicate spatial classification of suitability criteria using literature and GIS buffer analysis of the key nine (9) criteria selected to analyze and assess suitable dumpsite in the satellite city of Muhanga.

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Volume 9||Issue 2||Page 126-168 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

Table *3*:1 Suitability criteria for solid waste disposal site location

S.no	Criteria					
	Buffer distance (m per Class)	**Unsuitable -1**	**Least suitable -2**	**Moderate suitable -3**	**Suitable -4**	**Highly suitable -5**
1	Proximity to settlement	0-500m	500-1000m	1000-1500m	1500-2000m	>2000m
2	Proximity roads	0-200m	>1500m	200-500m	1000-1500m	500-1000m
3	Distance from River	0-200m	200–500m	500–1000m	1000–1500m	> 1500m
4	Distance from wetlands	0-500 m	500-1000m	1000-1500 m	1500-2000m	Over 2000 m
5	Protected areas	0-500m	500-1000m	1000-1500m	1500-2000m	>2000m
6	Slope (%)	> 30%	0%–5%	15%–30%	10%–15%	5%–10%
7	Soil type	Sandy/gravel	Sandy loam	Mixed/loam	silt	clay
8	LULC	Settlements/ water bodies/	Bareland/Rockyland	Agriculture	Forests	Grassland/Rangelands
9	Elevation	>2000m	1950-2000m	1850-1950m	1700-1850m	< 1700m

Source: Data compiled by author, 2024; A. Effat & N. Hegazy, (2012); Ayal (2021); Ebistu & Minale, (2013); Kenate, (2017); Ş. Şener et al., (2011); Thapa & Murayama, (2008)**.**

3.3 Environmental effects and potential risks of solid waste disposal site location in Muhanga satellite city

To achieve the third objective, the study analysed the environmental effects of solid waste disposal, and potential risks associated with site selection in the satellite city of Muhanga, emphasizing on key factors that affect the sustainability of waste management. The study presents findings from field interviews with 30 interviews, comprising 10 solid waste collectors and disposal workers (33.3%), 12 residents living near legal dumping site (40%) and 8 residents living nearby illegal dumping sites (26.7%). The reveal that that poorly managed waste disposal facilities in the satellite city of Muhanga are contributing to

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Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 126-168 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

significant environmental degradation. Reported consequences include air and water pollution, soil degradation, biodiversity loss, and a rise in disease-carrying pests. The figure 3.5 presents the environmental effects reported by respondents.

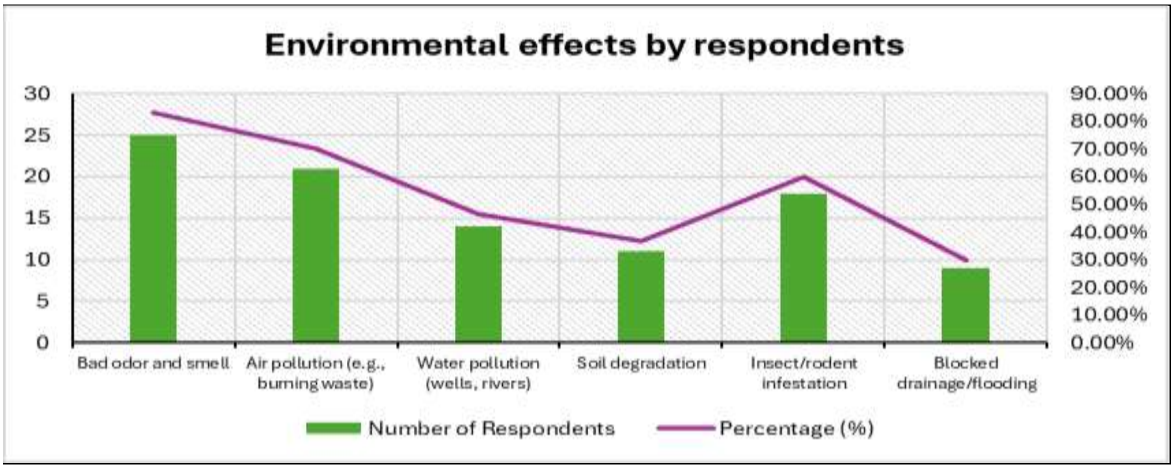

Figure *3*:5 Environmental effects reported by respondents

Based on findings in figure 3.5 respondents indicated considerable and diverse environmental consequences, with air pollution being the most generally cited (70%). This was mostly due to the open burning of combined, unsorted solid waste at both legal and illegal locations. Burning plastic, organic, and industrial waste emits particulate matter and harmful gasses, lowering air quality and posing health concerns. Residents near dumping sites expressed concerns about the continual exposure to smoke, and unpleasant smells, and dust particles in the air, especially during the dry season. These findings match with current literature that shows that incorrect municipal solid waste burning relates to respiratory difficulties and environmental deterioration (Kaza et al., 2020). According to Ramadan et al., (2022) waste burning practices contribute in releasing harmful pollutants such as methane, carbon dioxide, and particulate matter. This practice not only exacerbates climate change but also offers substantial respiratory health hazards for local residents. Research by Zhang, et al., (2024) underscore that the emissions from open dumps are a major contributor to urban air pollution, resulting in an increased urban environmental risks.

Water contamination was identified as another major concern, cited by 46.7% of respondents. Many reported that leachate from waste disposal facilities contaminate the drainage channels that channelling rainwater towards neighboring rivers, especially during the wet season. This poses a major health danger in locations where residents rely on surface water for household purposes. Similar patterns have been documented at Nduba dumping site in Rwanda, where uncontrolled dumpsites damage water sources via surface runoff and infiltration (Patrick et al., 2017).

Soil degradation was reported by 36.7% of respondents, who noted declining soil quality and reduced agricultural productivity near waste dumping sites. Some residents indicated that formerly fertile plots adjacent to these areas now yield poorly or have been abandoned altogether due to the presence of waste materials, and unpleased smells. Respondents expressed concern that land near dumpsites may no longer support sustainable food production. Concerns about the sustainability of food production near dumpsites are supported by numerous studies that underscore that the harmful impacts of waste materials

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 126-168 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

on soil quality and crop productivity. Njagi et al. (2016) and Obafemi et al., (2024) indicated that soils near dumpsites often contain heavy metals exceeding permissible levels, posing risks to crop health and human conception. Also, the widespread disposal of both biodegradable and non-biodegradable materials found to be a common practices on the illegal waste disposal, leading to soil pollution, reduced fertility, and making the land unsuitable for agricultural activity. This supports the findings of Abubakar et al. (2022) and Siddiqua et al. (2022), who found that waste mismanagement has a detrimental influence on soil health and affects land production.

Additionally, the existing waste dumping sites has led to a noticeable disturbance in local biodiversity. Several participants reported an increase in populations of scavengers, such as rats, flies, and wildlife dogs. The dumping sites near wetlands and forests areas disrupt local ecosystems, threatening wildlife and plant species. According to Van Den Berg & Duong, (2018) inadequately waste disposal result in habitant destruction which diminishes biodiversity and disrupt natural ecological balance.

Insect and rodent infestation was among the most frequently reported issues, cited by 60% of respondents. Accumulated, uncovered waste creates ideal breeding grounds for flies and mosquitoes, and serves as a food source for rats and stray animals. Households located near dumpsites reported recurrent infestations, which have contribute to a rise in hygiene-related illnesses. These findings are consistent with public health studies that link inadequate waste management to outbreaks of vector-borne diseases in urban and peri-urban settings (Pruss-Ustun et al., 2006). Moreover, 30% of respondents identified flooding and blocked drainage as recurring problems linked to illegal dumping practices. Waste often clogs waterways and culverts, particularly in low-lying areas, causing water stagnation and localized flooding. These issues are especially severe during the rainy season, leading to property damage and creating ideal conditions for mosquito breeding. Residents emphasized the need for urgent interventions to improve drainage infrastructure and prevent waste disposal in environmentally sensitive zones.

Field data clearly show that current waste disposal facilities in Muhanga District are significant contributors to environmental deterioration, particularly in areas near informal or poorly managed dumpsites. Air and water pollution, soil degradation, biodiversity loss, and an increase in disease-carrying pests are among the serious consequences described by affected populations. Inadequate infrastructure, minimal regulatory monitoring, and restricted community input in site selection procedures all contribute to the problem. These findings emphasize the need for comprehensive environmental planning, the implementation of adequate solid waste management systems, and the promotion of participatory decision-making in the face of rising urbanization in the satellite city of Muhanga.

3.4 Suitability screening, identification and reclassification of criteria

3.4.1 Soil criterion characteristics

Soil properties, including soil textures and permeability, in a given area are determined by variety of interactive factors, such as parent material, climate (including rainfall and temperature), biological elements (like flora and fauna), topography and the influence time. Soil textures is explained by the relative amount of sand, silt, and clay particles compose a

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Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 126-168 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

given soil. The choice of an appropriate soil texture identifying location for dumping sites is critical to minimize the environmental risks, such as groundwater contamination and soil permeability and the ability to prevent leachate infiltration.

The soil map of the study area was sourced from the world soil map developed by FAO/UNESCO. The study area map was extracted and digitized within GIS environment, and its thematic map was generated. As indicated in soil map 3.6 below, the majority of the study area is dominated by clay loam, clay and sandy clay loam, and sandy loam in that order.

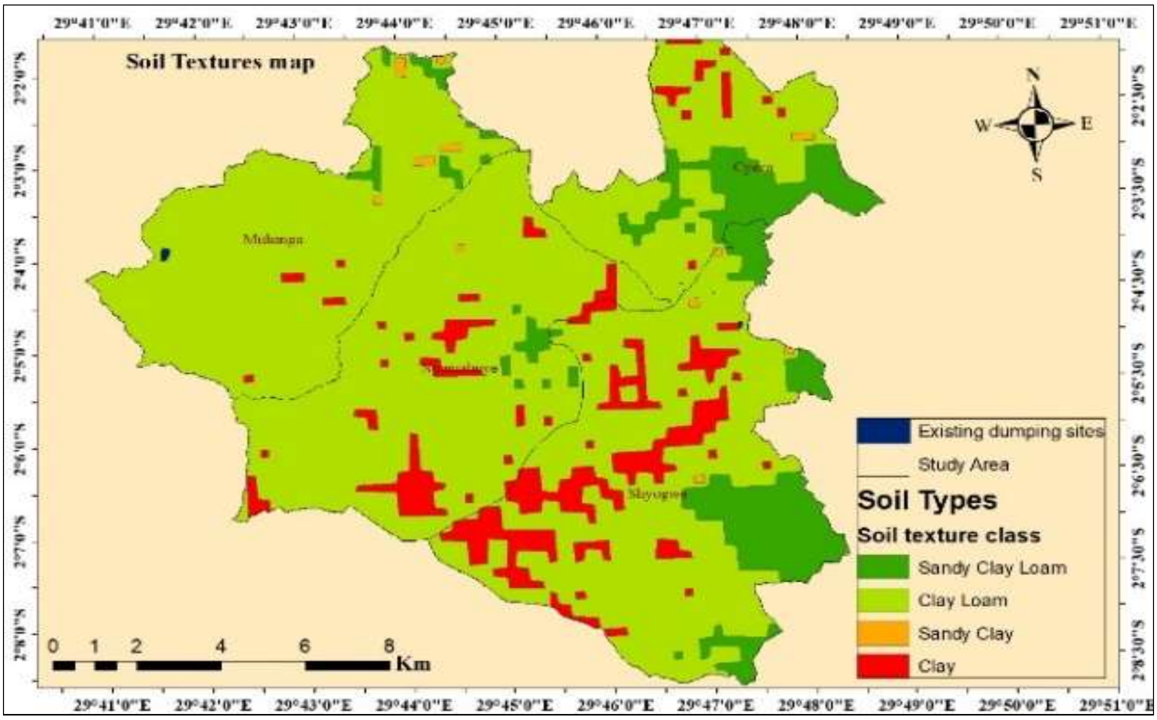

Figure *3*:6 Soil map within Muhanga satellite city

The soil texture affects soil permeability and porosity, thereby moderating vertical and horizontal movement of contaminants (P & Tejaswini N. Bhagwat, 2018). Accordingly, clay soil and clay loam are highly preferred for dumping site locations due to its very low permeability minimizes leachate infiltration and reduces risks of groundwater contamination (Vijayalakshmi et al., 2020). Indicate of below table 3.2, the highly suitable soil class is clay soil, covering 8.7% of the area. Its low porosity make it highly suitable for dumping sites location. The dominant soil type in the study area is clay loam, which covers 80%. Due to its balance water-holding capacity and moderate permeability, clay loam soil also considered as suitable choice for dumping sites (Vijayalakshmi et al., 2020). The remaining two soil types in the study area are sandy clay loam and sandy clay, covering 10% and 0.4% of the area, respectively.

Table *3*:2 Area coverage and Soil suitability Classes

Factor	Criteria value	Suitability classes	Suitability ranks	Area (ha)	(%)
Soil types	Clay	Highly suitable	5	1541	8.7
	Sandy loam	Moderately Suitable	3	73	0.4
	Sandy clay loam	Least suitable	2	1854	10.5
	Clay loam	suitable	4	14153	80.3
Total				**17621**	**100**

Accordingly, approximately 9% of the study area is highly suitable, 80% suitable, 0.4% moderately suitable, and then 10% is least suitable area for solid waste disposal site location as presented by figure 3.6.

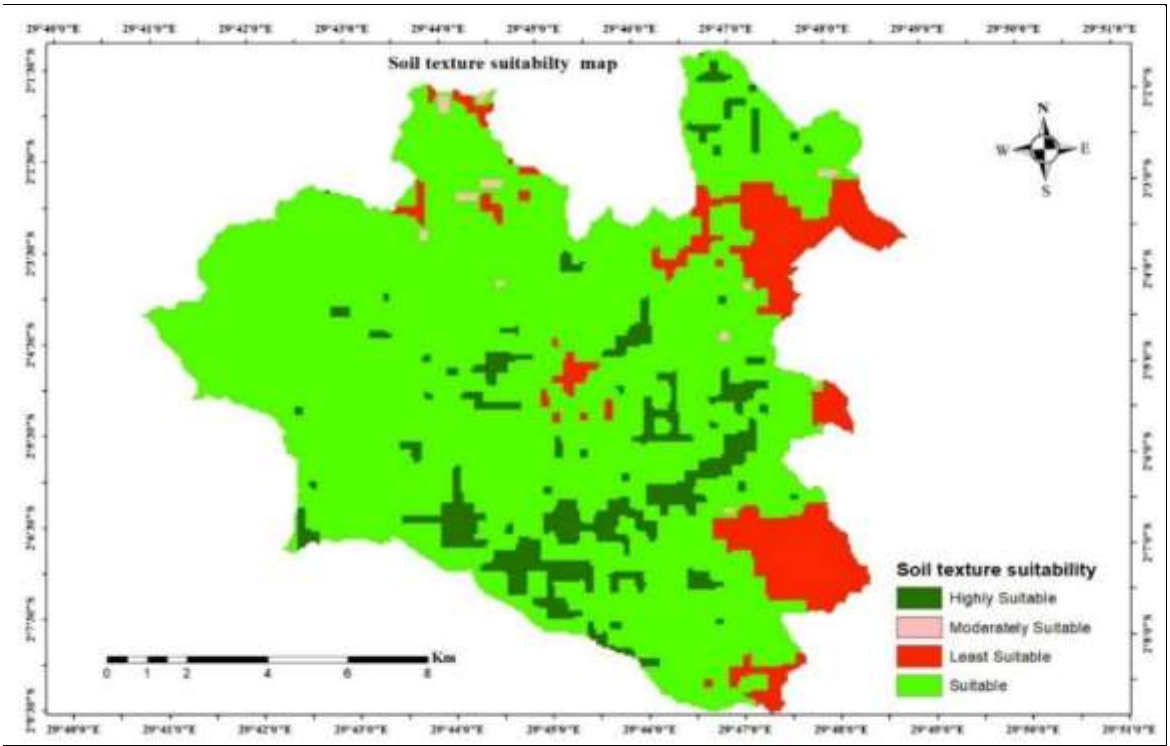

Figure *3*:7 Suitability Soil Map of the Study area (Author, 2025)

3.4.2 Topography criterion

Topography refers to the arrangement of ground features within an area of interest, with slope and elevation being key factors in determining the suitability of a solid waste disposal site location. These topographical elements are essential for determining stability of structure, accessibility and effectively managing water drainage around the site. Topography also has a significant impact on disposal capacity, drainage and long-term operation of the site. Steep slopes tend to increase runoff and runoff, making them less suitable for dumping sites whereas flatter areas are often suitable (Abdulwaheed et al., 2024). Moreover, disposal sites in floodplain areas with high water flows must be avoided due to the possibility of polluting waster systems. Uplands areas with outward water flows are preferred to minimize risks of groundwater pollution (Lee et al., 2016).

3.4.3 Elevation

Elevation has significant effect upon the location of solid waste disposal site, impacting water drainage, structural stability, and environmental impact. According to Şener et al. (2006) elevated sites are frequently selected because they improve natural drainage, reduce surface water collection, and lower the risk of leachate pooling. On the other hand, low-lying areas or depressions influence waterlogging, increasing the possibility of groundwater pollution. Another significant factor to consider for elevation is the potential of flooding. Low-elevation locations in floodplains are vulnerable to pollution spread during floods, whereas elevated sites are safer and less expensive to operate (Abdulwaheed et al., 2024). Elevated locations can give higher structural stability, particularly when the soil is composed of low-permeability elements like clay, which assist reduce leachate seepage (B. Şener et al., 2006). By employing ArcMap 10.8 software, elevation map of Muhanga satellite city shown figure 5 was prepared using data from shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) available on the United States Geological Survey (USGS) (https://earthexplorer.usgs.gov) website.

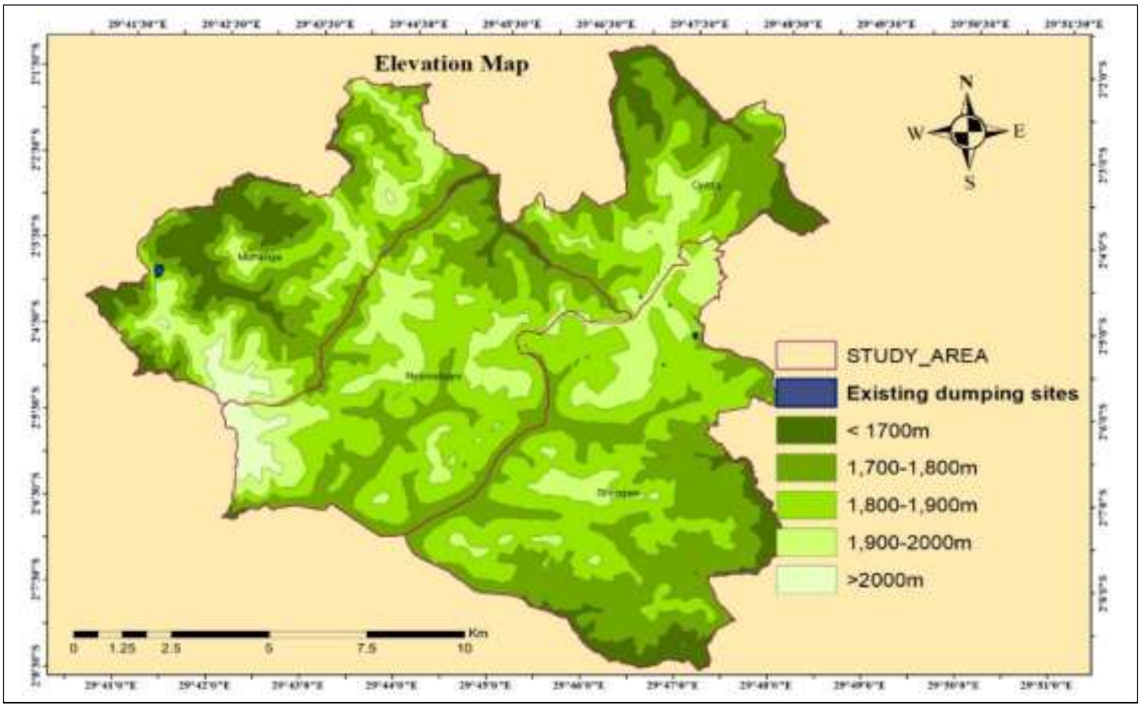

Figure *3*:8 Elevation map of Muhanga satellite city

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Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 126-168 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

Based on the altitude map, Muhanga satellite city is categorized into four elevation ranges: above 2000m, between 1800-1900m, between 1700-1800m and below 1700m. The map depicts that more than half of city's area has an altitude above 1800m above the mean sea level (MSL). High altitude areas are unsuitable for waste disposal sites due to their challenging accessibility, increase the risks of erosion, potential for contamination of downhill water sources and environmental vulnerability (Majid & Mir, 2021). Date table 3.3 and figure.3.8 present the elevation suitability classes and their coverage areas within the study area

Table *3*:3 Elevation suitability classes and their coverage areas

S.N.0	Elevation classes	Level of suitability	Ranking	Area (ha)	(%)
1	<1700m	Highly suitable	5	1705	9.7
2	1700-1800m	Suitable	4	5928	33.6
3	1800-1900m	Moderately suitable	3	6628	37.6
4	1900-2000m	Least suitable	2	3007	17.1
5	>2000m	Unsuitable	1	350	2.0

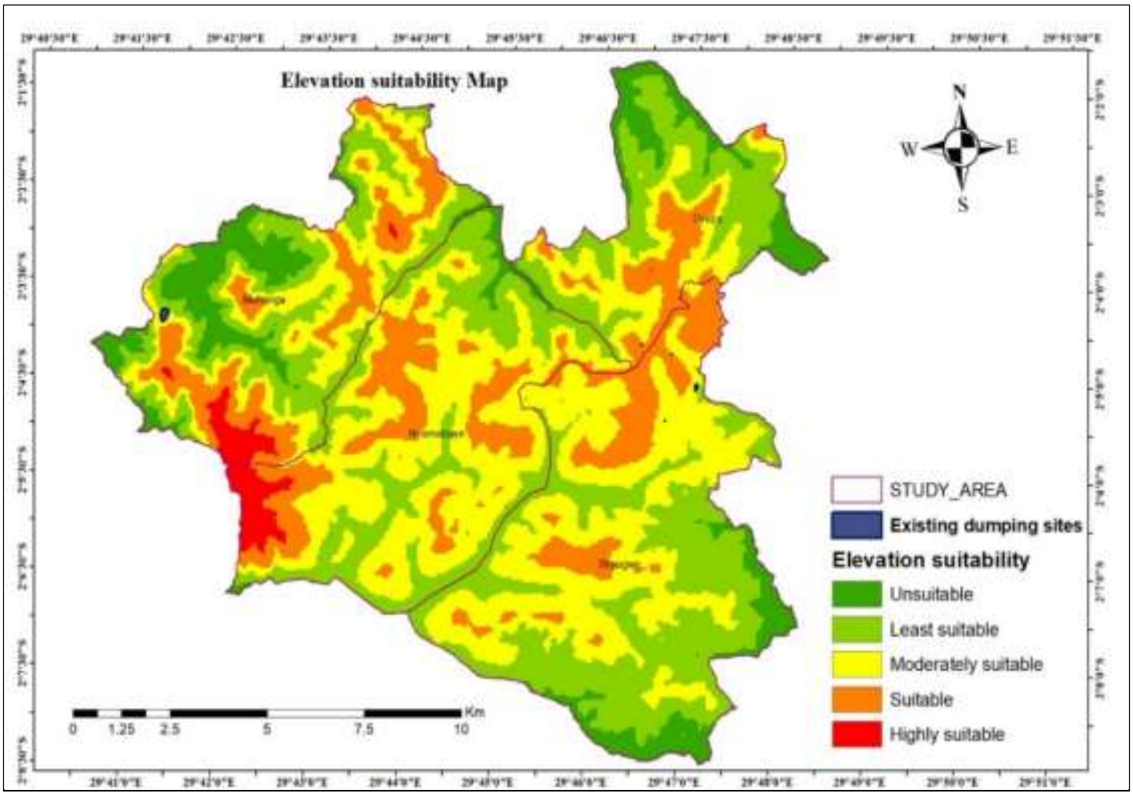

Figure *3*:9 Elevation suitability in the study area

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Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 126-168 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

3.4.4 Slope

Similar to altitude map, a slope map of an area is also produced from USGS DEM, available on (https://earthexplorer.usgs.gov) website. The data is then reclassified on scale of 1 to 5 in raster format using GIS (10.8) environment to produce a thematic map, as shown in in Fig. 3.9. The slope of an area is related to its topography, which determining key parameters such as surface flow velocity, runoff characteristics, soil water contents and erosion potential. It is an essential factor in identifying suitable location for waste disposal sites.

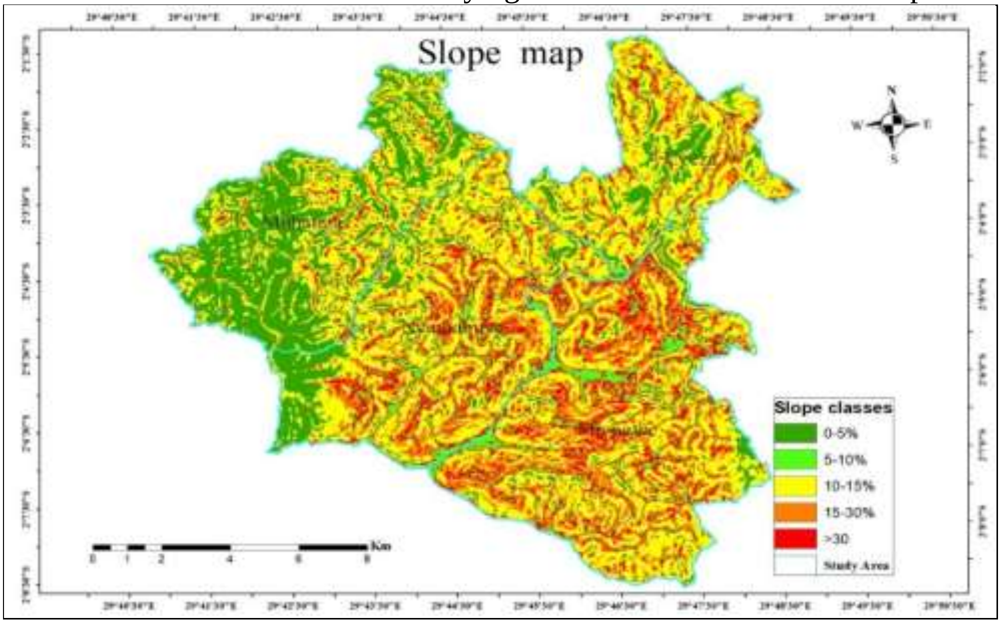

Figure *3*:10 Slope Map of Muhanga satellite city

The slope analysis of the study area reveals that the majority of Muhanga satellite city falls within the 10-15% slope class, covering 44% on the total area. This is followed by the 0-5% slope class , which accounts for 20%, the 15-30% class at 18% , the 0-5% class at 12%, and an area with slope above 30% make up 6% of the total area as illustrated in table 3.3.

Table *3*:4 Slope Suitability Classes in Muhanga satellite city

No	Slope Class	Level of Suitability	Rank	Area (ha)	(%)
1	0-5%	Least Suitable	2	3475	20
2	5-10%	High suitable	5	1010	6
3	10-15%	Suitable	4	7612	44
4	15-30%	Moderately suitable	3	3048	18
5	>30%	Unsuitable	1	2157	12
Total				**17302**	**100**

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Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 126-168 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

The figures in table 3.4 indicate that 6%, 44%, 18% of the total area are categorized as highly suitable, suitable and moderately suitable, respectively, for soil waste disposal site. Meanwhile, 20% and 12% of the area are categorized as least suitable and unsuitable areas for solid waste disposal site as shown in figure 3.10 below. This shows that the slope is not a significant challenge for solid waste disposal site locations in the satellite city of Muhanga. Appropriate slopes for solid waste disposal site locations should neither be too steep nor to too flat to minimize associated environmental risks, including increased leakage, runoff drainage, erosion and potential instability. Numerous studies highlight ideal slope categories for solid waste disposal sites. Ş. Şener et al. (2011) suggest that slope ranging from 8% to 12% are highly suitable for solid waste disposal site location. Similarly, Desta et al. (2023) identify the slope between 2% to 8% as the most suitable site for solid waste disposal locations. In this study, slope between 5 to 10% are considered highly suitable for solid waste disposal sites locations.

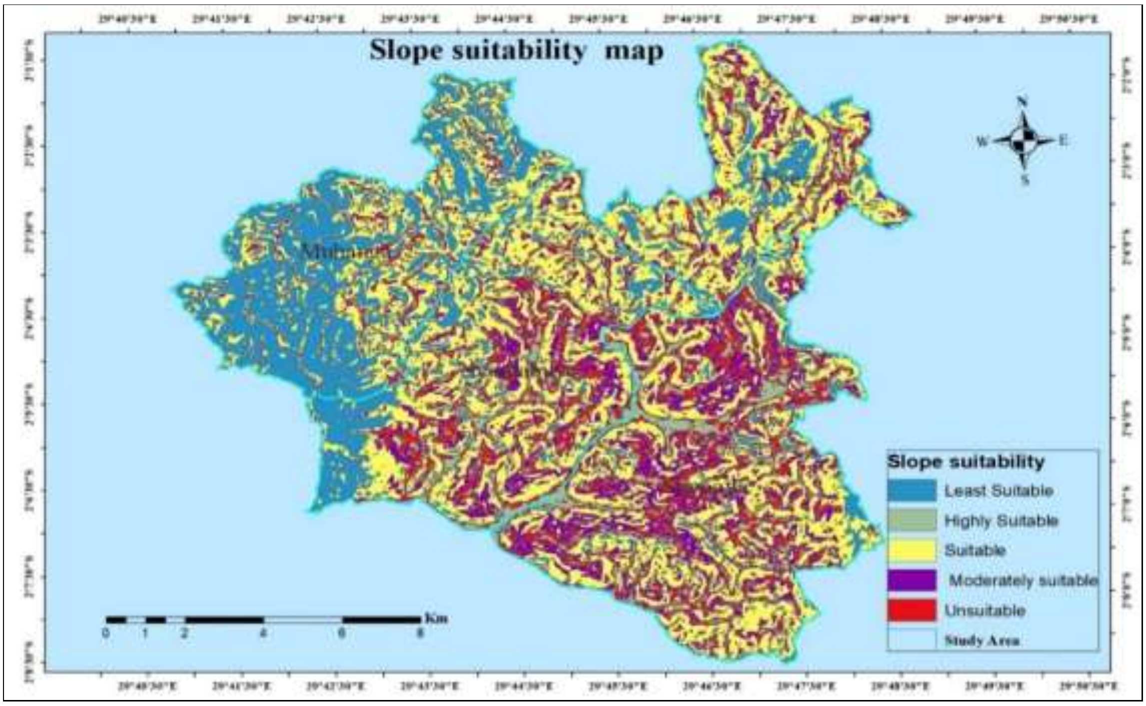

Figure *3*:11 Slope suitability map of the study area

3.4.5 Road Network

Roads belong the key assessment criteria to consider when analysing suitable location for solid waste disposal site. Therefore, data of existing roads networks in the study area were obtained from open street map (www.openstreetmap.org) and using ArcGIS (10.8) software to produce a thematic roads network thematic map. Ideally, solid waste disposal site should be easily accessible and located at an appropriate distance to road to ensure efficient waste transportation and minimize associated costs. Moreover, waste disposal site should not be very close to roads, as proximity may pose public health issues. At the same time, they should not be too faraway to avoid excessive access cost (Majid & Mir, 2021; Mohammed et al., 2019). Various buffer distances from roads have been suggested in the literature for determining suitable locations for solid waste disposal sites. Chabuk et al. (

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 126-168 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

2017) and A. Effat & N. Hegazy, (2012) set 500m buffer, while Molla (2024) applied 0-400 meters buffer on both sides of the road as the minimum distance within which a solid waste disposal site should not be located. However, a buffer distance of 500 to 1000 meters has identified as the safest distances (Chandel et al., 2024; Desta et al., 2023; L. Kareem et al., 2021). In this study, Multiple Ring Buffer tools were employed to create buffer classes around the roads with 0-200m, 200-500m, 500-1000m, 1000-1500m, and above 1500m distance ranges as shown in figure 5 we see in figure 3.11 below.

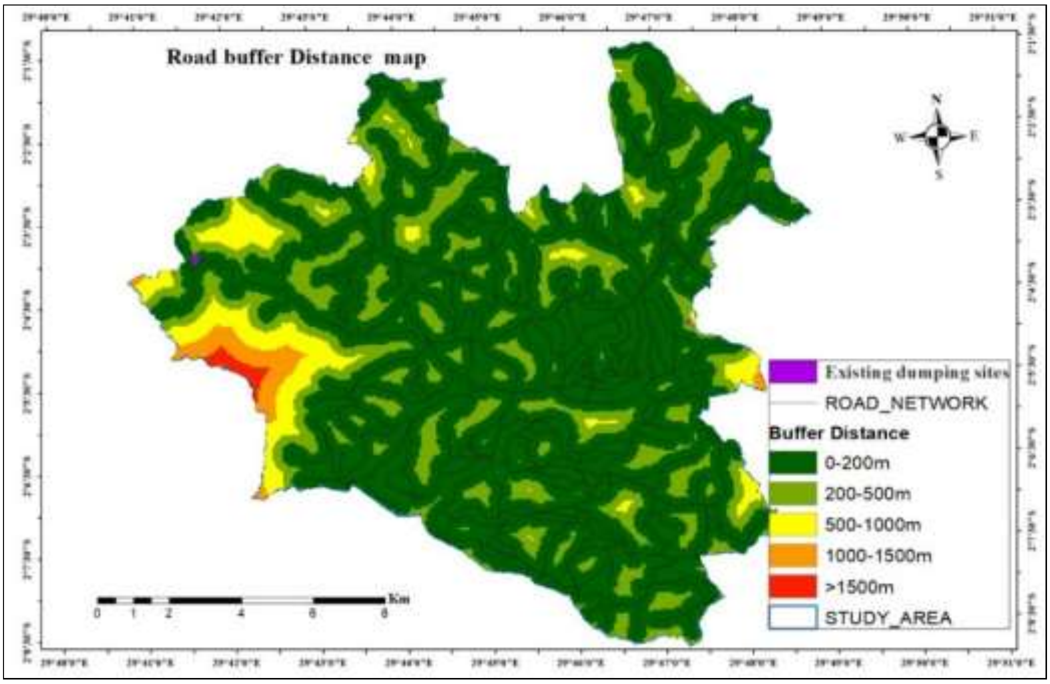

Figure *3*:12 Road buffer distance map

The accessibility was reclassified and scandalized based on the fact that nearest and faraway waste disposal sites are unsuitable and thus excluded from analysis. As a result, buffer distance of 0-200 meters and greater than 1500 meters were unsuitable and least suitable, respectively. However, buffer distance ranging from 200 up to 1500 meters were assigned suitability based on their preference. The highly suitable location for waste disposal site is 500 to 1000 meters from the roadways, 1000 -1500 meters is suitable, while the moderately suitable site is 200-500 meters. In general, suitability of waste disposal site location decreases with increasing distance between 500 and 1500 meters. This is owing to expenses associated with transportation as well inaccessibility of the area. Table 3.5 and figure 3.12 illustrate the weight assigned and suitability level with their area coverage.

https://doi.org/10.53819/81018102t2486

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 126-168 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

Table *3*.5 Road network suitability in the study area

No	Suitability Classes	Level of suitability	ranks	Area (ha)	(%)
1	>1500m	Least suitable	2	4346	13.05
2	200-500m	Moderately suitable	3	6095	19.71
3	1000-1500m	Suitable	4	2894	9.36
4	500-1000m	Highly Suitable	5	4016	12.99
5	0-200m	Unsuitable	1	13577	43.90
Total				**30928**	**100**

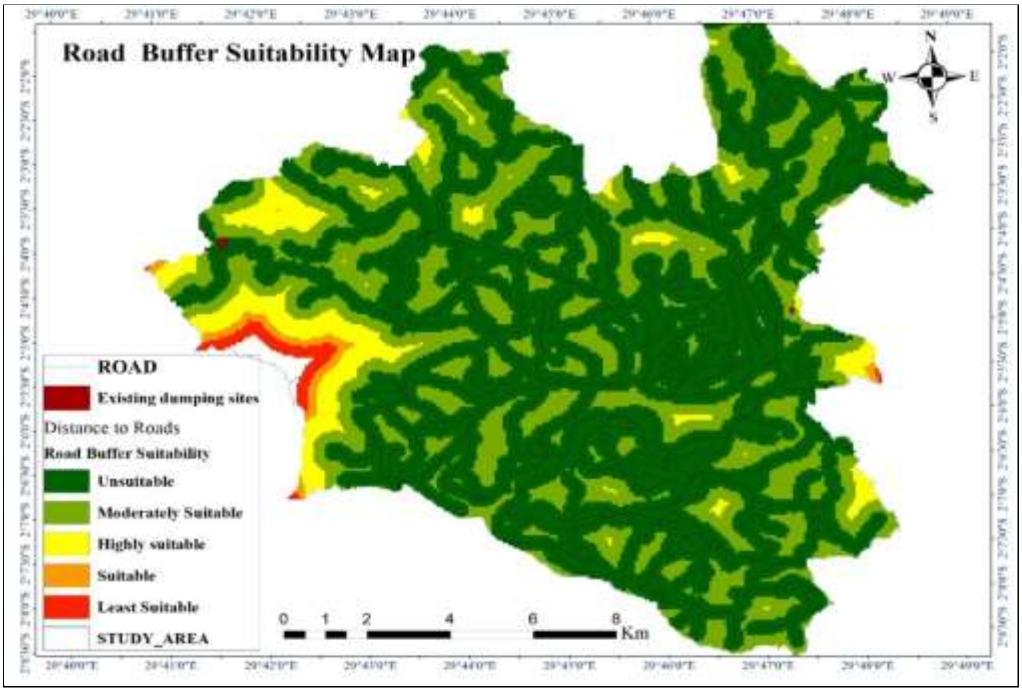

Figure *3*:13 Road network Suitability Buffer map

According to the suitability table (table 6) the reclassified distances analysis indicate that 12.9% of the area is classified as highly suitable for solid waste disposal sites, followed by 9.36% as suitable. In contrast, 13.05% of the total area is categorized as least suitable, 19.71% as moderately suitable, and 43.9% as unsuitable area for waste disposal sites location within the study area.

3.4.6 Proximity to rivers/streams.

The predominant surface water bodies exist in the study area are streams. Waste disposal sites should not be located at a safe distance from river, stream and lakes. As the distance

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Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 126-168 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

between water bodies and waste disposal sites decreases, the likelihoods of water contamination increases. The pollution poses high risks of environmental, public health and economic challenges (Kassenga & Mbuligwe, 2009). In this study, river/streams were generated from the Digital Elevation Model (DEM) of the Satellite city of Muhanga using spatial analyst hydrology extension, resulting in the generation of a stream network, as shown in figure 3.13 below.

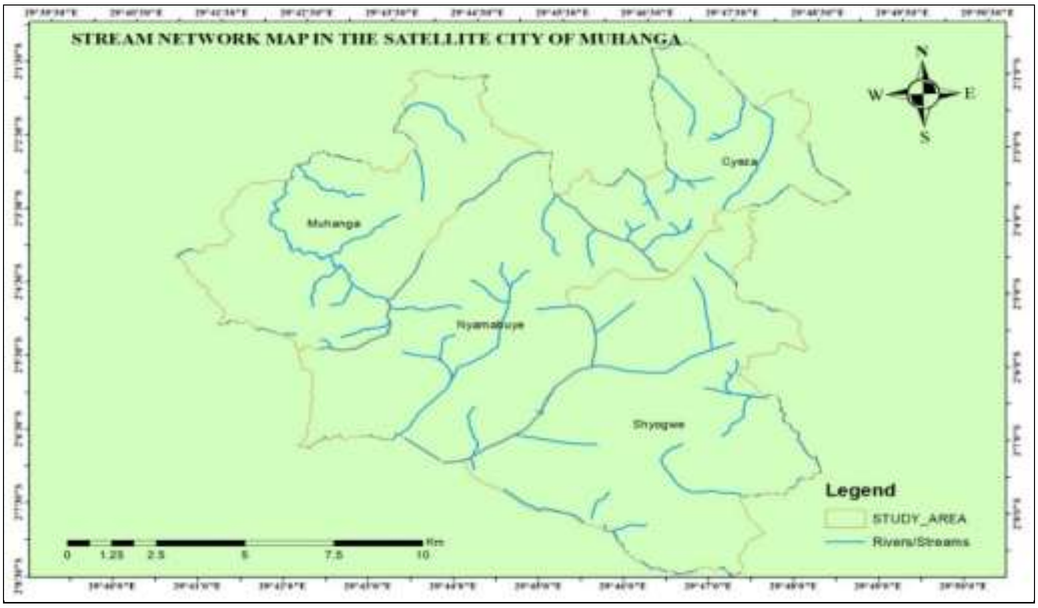

Figure *3*:14 Map of stream network in the satellite city of Muhanga.

To prevent surface water pollution, waste disposal site should not be located nearest rivers, stream or lakes. Polluted runoffs from waste disposal can negatively affect surface water quality. Consequently, to minimize such pollution various researchers have proposed minimum buffer distance criteria for waste disposal site location. For instance, Khan & Samadder, (2015) used 100 meters as a minimum buffer distance, while the Rwanda Environmental Management Agency (REMA) (2010) set a 300 meters buffer distance (https://rema.gov.rw). Additionally, Ali & Ahmad (2020); Aziz (2022) and Ampofo et al.(2023) proposed a 500 meters of buffer distance whereas Sk et al. (2020) applied a 200 meters buffer distance. Further more preferable buffer distance proposed in Desta et al., (2023). Therefore, four (4) distinct zones as presented in figure 3.14, were defined. Area further from stream are considered suitable for waste disposal site location, while those closer to streams considered unsuitable and least suitable.

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 126-168 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

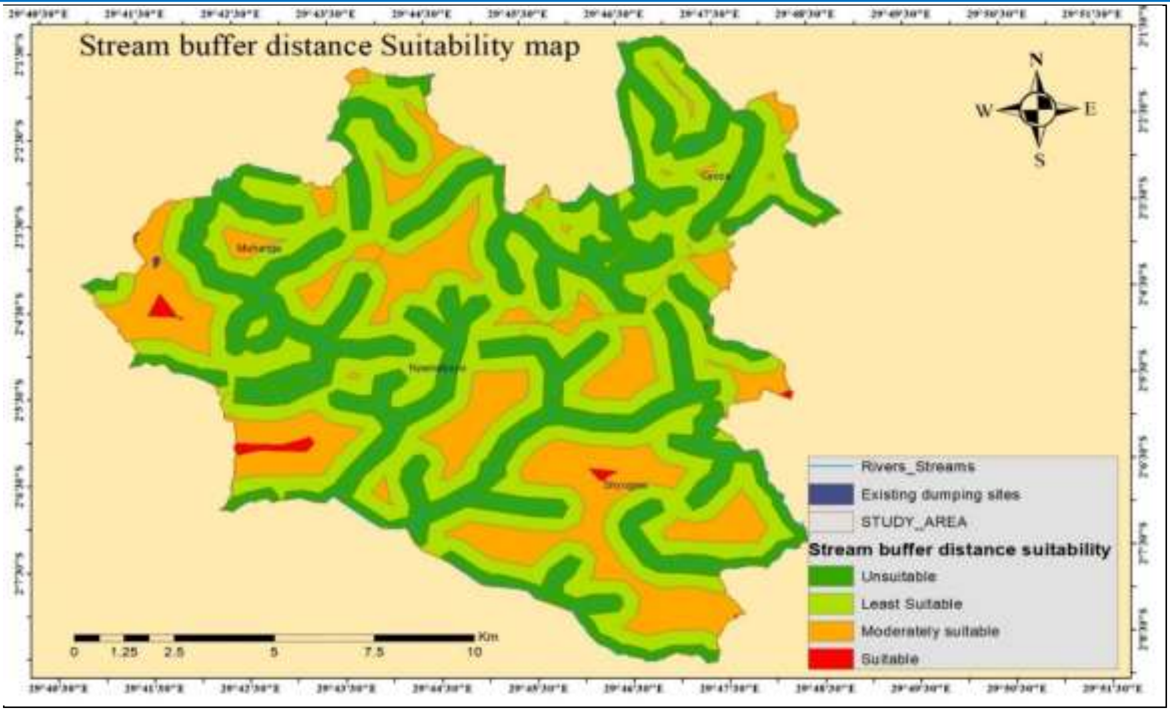

Figure *3*:15 Map of stream buffer distance suitability in the study area

Thematic map of stream buffer distance was produced using multiple ring buffer extension in a GIS environment. This process created multiple buffer polygons within the following distance: 0-200m, 200-500m, 500-1000m, 1000-1500m and greater than 1500m. The buffer area within 0-200m was excluded to prevent waste disposal leakage into surface water. Table 3.7 presents a summary of stream buffer distance suitability in the satellite city of Muhanga.

Table *3*:5 Stream buffer distance suitability

S.no	**Buffer distance in (m)**	**Suitability classes**	**Ranks**	**Area (Ha)**	**%**
1	0-200m	Unsuitable	1	6311	35.8
2	200-500m	Least suitable	2	7432	42.2
3	500-1000m	Moderately Suitable	3	3773	21.4
4	1000-1500m	Suitable	4	96	0.5
Total				**17612**	**100**

Figures in table 3.7 show that 35.8 % of the study area was excluded from siting process due to presence of surface water, rendering it unsuitable area for waste disposal site location. In contrast, only 0.5% of the area is classified as suitable for waste disposal, while 21.4 % and 42.2% of the study area were categorized as moderately suitable and least suitable, respectively.

3.4.7 Proximity to built-up areas

The closeness of a waste disposal to built-up areas is an important environmental criterion for waste disposal site location. Settlements, commercial zones, government and private institutions, schools, health centres, religious institutions, educational facilities, and other social service areas are all examples of built-up area. Solid waste disposal sites should be located faraway densely populated areas to minimize irreversible public and environmental (Kebede & Ayenew, 2023). Results from analysis conducted to see the built-up conditions revealed that about 3900 hectares of the toral area is covered by built -up areas. Such built-up area covered by human settlements, commercial areas, government and private institutions, public and private schools, health centers, educational institutions, industrial area, religious institutions and other social services. Any type of waste disposal should be kept at a safe distance from densely populated regions, since these locations play an important role in assessing solid waste disposal site appropriateness. Placing disposal facilities away from densely populated regions helps to reduce unpleasant smells and health dangers (Mussa & Suryabhagavan, 2021). Built-Up areas and land cover of the satellite city of Muhanga were obtained from Esri Land Cover/Sentinel-2-10 Meter Land use/Land Cover accessible via ArcGIS Living Atlas. Consequently, spatial analyst and multiple ring buffer tools were utilized to extract and prepare buffer zones around the built-up areas, as presented in figure 3.15 below.

Waste disposal sites must be at least one kilometer away from residential areas, religious areas, educational institutions and other social services. Furthermore, it should be built in locations with little economic or ecological importance. Various researchers have suggested different criteria for the buffer distance in identifying suitable location for solid waste disposal sites. Ali & Ahmad (2020); Ngwijabagabo et al. (2020); Aziz (2022); Ampofo et al. (2023) suggested buffer distances ranging from 500 meters to over 2000 meter as an optimal for waste disposal sites. Contrarily, Nwosu & Pepple (2016) and Ş. Şener et al.(2011) proposed large buffer distances of 3000 meters and 8000 m, respectively, for the ideal location for waste disposal sites.

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 126-168 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

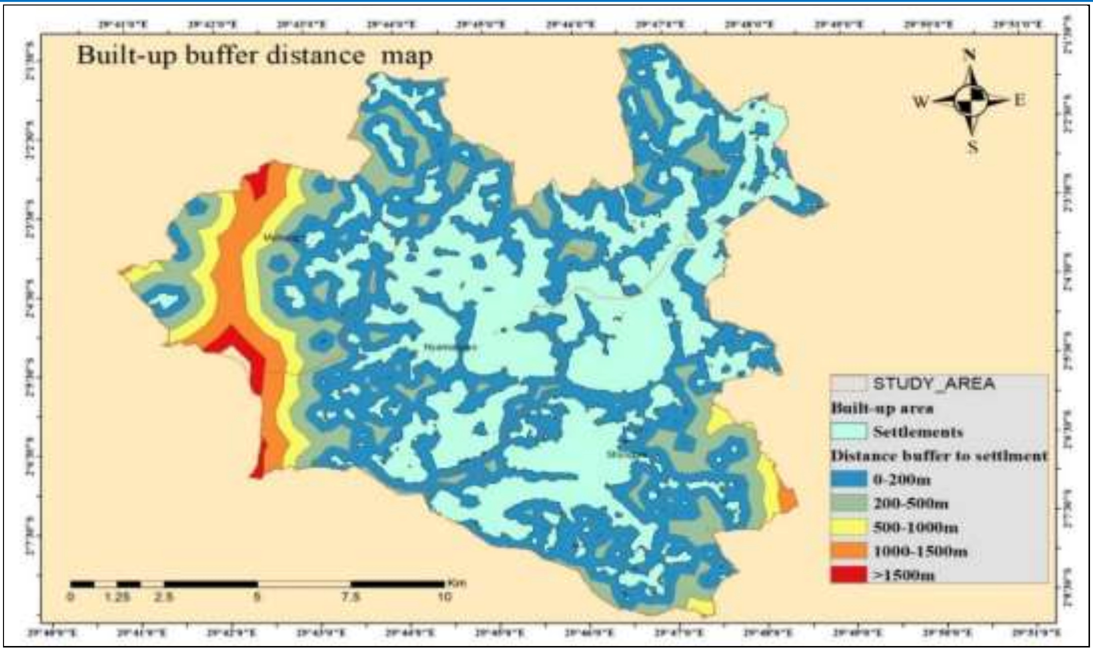

Figure *3*:16 Built-Up proximity buffer map

Various research proposed varied buffer distance for built-up area suitability. In this study, a minimum distance of more 500 meters from build-up areas was considered appropriate. But, distances less than 500mters were classified as least suitable to unsuitable location for waste disposal site location. Table 3.8 and figure 3.16 illustrate the weight assigned and suitability classes with their area coverage.

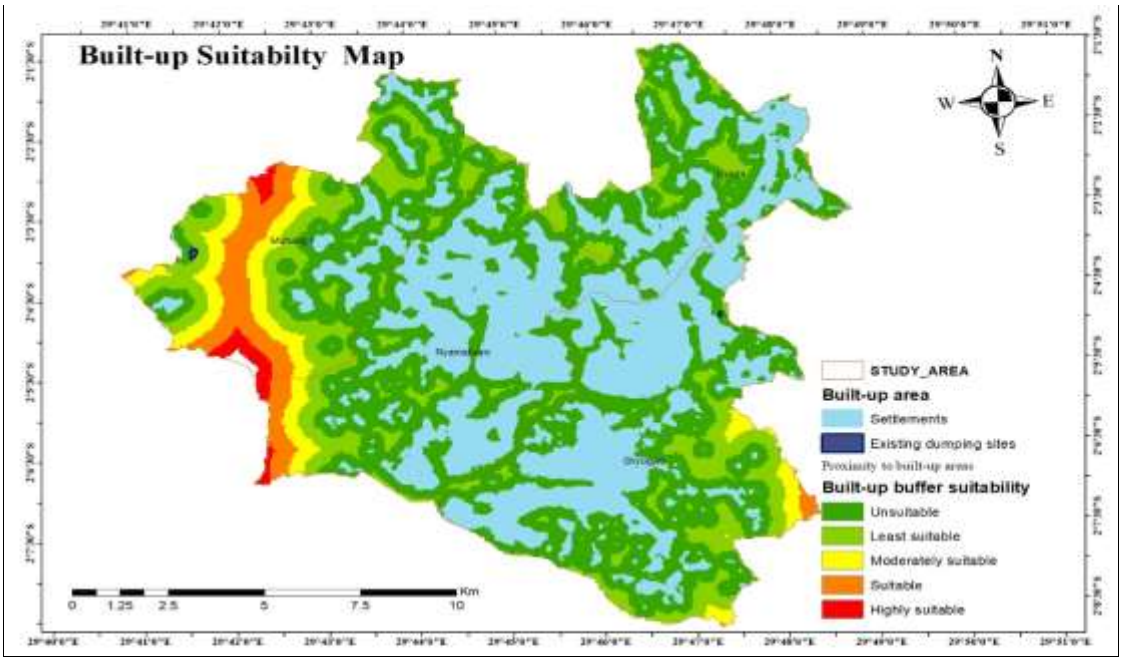

Figure *3*:17 Built-up Suitability map

Table *3*:6 Built-Up suitability in the Study Area

S No	Buffer distance in (m)	Suitability classes	Ranks	Area (ha)	(%)
1	0-200 m	Unsuitable	1	8126	76.96
2	200-500 m	Least suitable	2	1405	13.31
3	500-1000 m	Moderately suitable	3	487	3.61
4	1000-1500 m	Suitable	4	439	3.16
5	>1500m	Highly suitable	5	102	0.97
Total				**10559**	**100.00**

The figures in table 3.8 present that approximately 1% of the total areas is classified as highly suitable , whereas 76.9% is considered unsuitable for waste disposal sites. Additionally, 13.3% is categorized as least suitable, 3.6% as moderately suitable, and 3.2% as suitable for solid waste disposal sites location.

3.4.8 Proximity to protected areas

In this study, protect area/sensitive places in the satellite city of Muhanga include schools, religion institutions, administration offices, hotels, health centers, markets places, playing grounds, and aerodrome site. To minimize potential risks to human health, a dumping site should not be located within a buffer of 500 meters from the sensitive areas mentioned above. In this research, the X and Y coordinates for the listed protected/sensitive places were recorded using GPS during the field survey. Then, using GIS 10.8 software, a multiple Ring Buffer tool was applied to create the buffer distance around these protected areas/sensitive areas, a shown in figure 3.17 below.

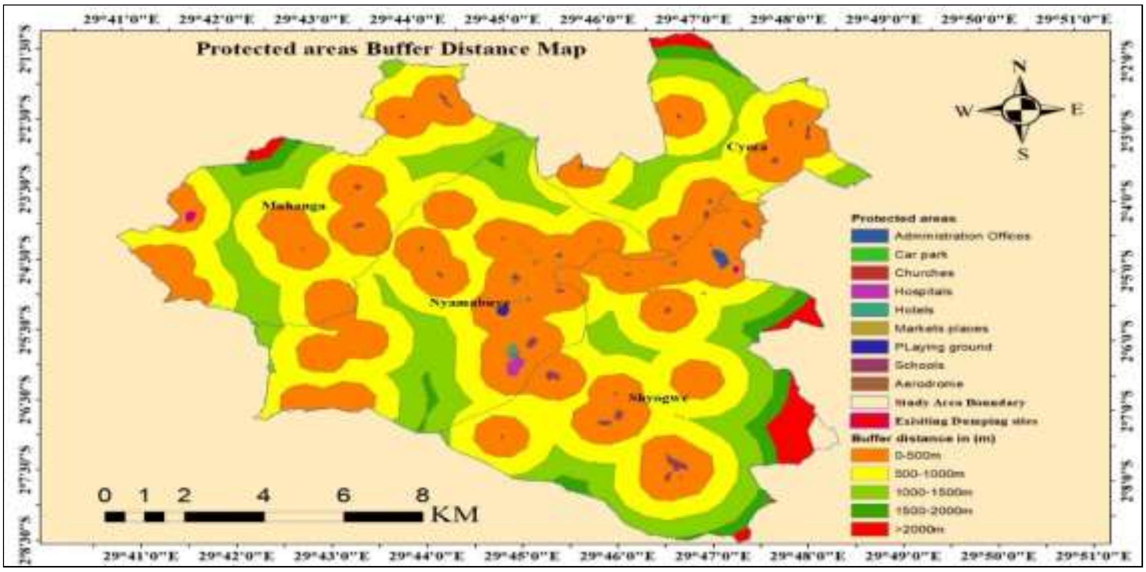

Figure *3*:18 Protected Buffer distance map

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 126-168 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

In this study, a buffer distance of 500 meters was considered the minimum buffer limit to identify location for solid waste disposal sites. Accordingly, five buffer distance were reclassified: 0-500 meters as unsuitable, 500 -1000 meters as least suitable, 1000 -1500 meters as moderately suitable, 1500 - 2000 meters as suitable, and areas more than 2000 meters as highly suitable for solid waste disposal site location. Analysis results of suitability levels with their corresponding areas is shown in table 3.9 and figure 3.18. Based on findings, highly suitable area account for 9.7%, while suitable areas account for 9.8%. Additionally, 22.4 % of the total area is categorized as moderately suitable, 23.3 % of the total area as least suitable, whereas 33.8% of the study area has been classified as unsuitable for solid waste disposal site location.

Table *3*:7 Protected Area Suitability Class

N.0	Buffer Distance (m)	Suitability level	Ranks	Area (ha)	(%)
1	0-500m	Unsuitable	1	5465	33.76
2	500-1000m	Least Suitable	2	3665	23.31
3	1000-1500m	Moderately Suitable	3	3528	22.44
4	1500-2000m	Suitable	4	1536	9.77
5	>2000m	Highly Suitable	5	1527	9.71
Total				**15721**	**100.0**

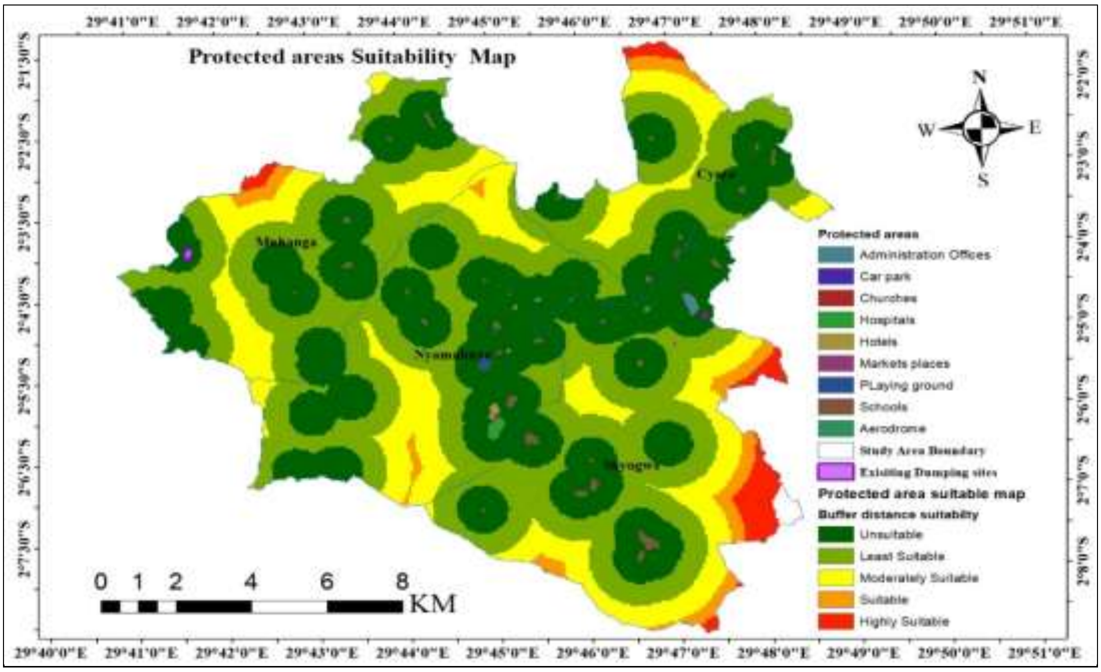

Figure *3*:19 Protected Area Suitability Map

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 126-168 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

4.3.8 Proximity to wetlands areas.

Wetlands, being environmentally sensitive habitats, can significantly impacted by nearly by waste disposal sites, resulting in water and soil contamination, disruption of biodiversity , and noncompliance with environmental standards. Wetlands provide critical role including water publication, floods control, and habitant for diverse species (Ferreira et al., 2023). Existing wastelands areas in the study area were obtained from shuttle Radar Topography Mission (SRTM)Water body data available on the United States Geological Survey (USGS) (https://earthexplorer.usgs.gov). therefore, spatial analyst and multiple ring buffer tools were utilized to extract and prepare buffer zones around the wetland areas, as presented in figure 3.19 below.

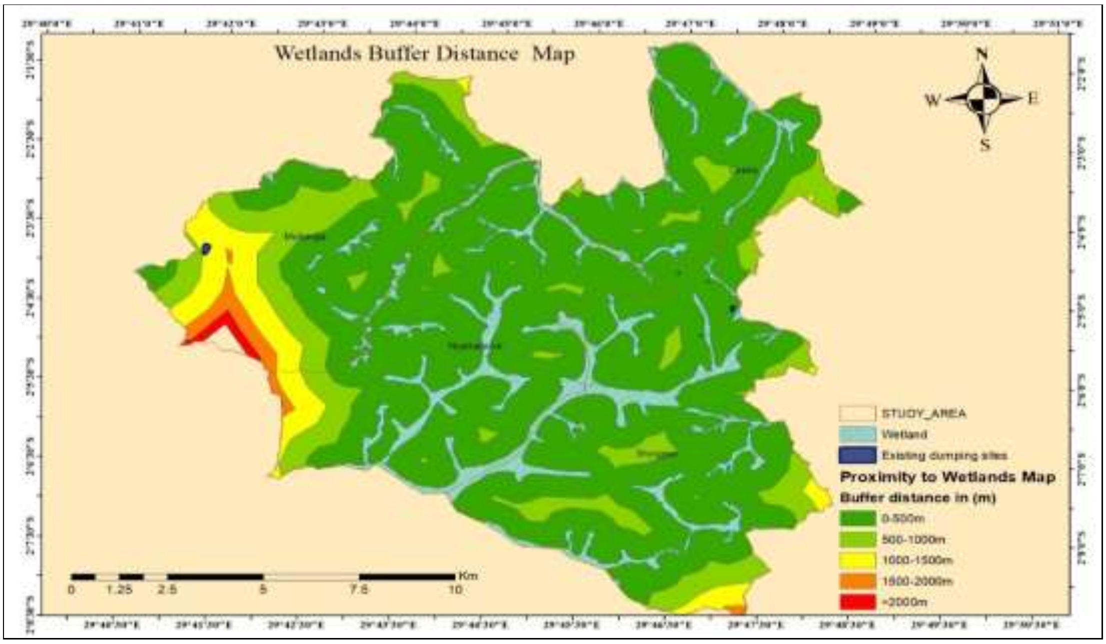

Figure *3*:20 Wetlands buffer distances map

According to the literature, buffer distances surrounding wetlands vary to protect water quality, offer wildlife habitat, and preserve the ecological integrity of the wetlands. The distances of these buffers varies based on the kind of wetland, adjacent land use, and unique environmental challenges. Mujtaba et al. (2024) propose optimal buffer distance for solid waste disposal site selection varying between 500 to 1000 meters, while Ouma et al. (2011) and (Gebremedhin et al., 2023) suggest a buffer distance more than 2000 meters. Most preferable buffer distance suggested in Ngwijabagabo et al. (2020). Accordingly, five (5) distinct buffer distances as presented in figure 3.20 and table 3.10 , were defined. Area further from wetland/swamp are considered suitable for waste disposal site location, while those closer to Wetlands considered unsuitable and least suitable.

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 126-168 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

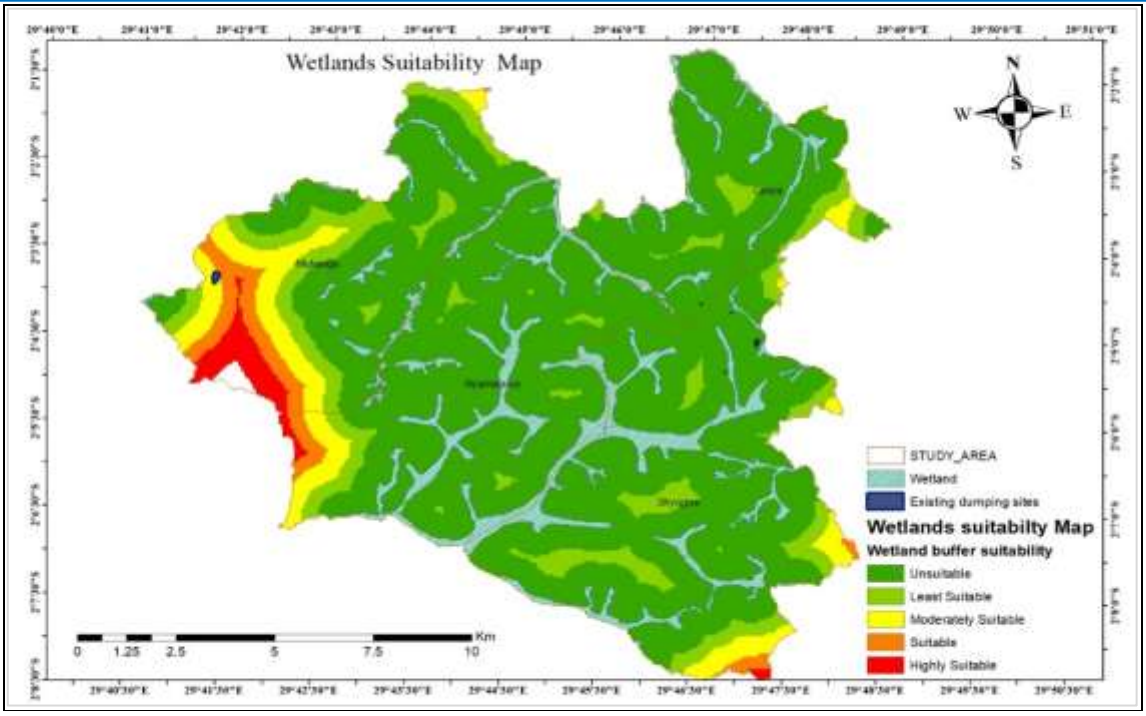

Figure 3:21 Wetland buffer suitability map

Table 0:8 Wetland Suitability in the study area

S.no	Buffer distance in (m)	Suitability classes	Ranking	Area (ha)	(%
1	0-500	Unsuitable	1	13976	79.53
2	500-1000	Least Suitable	2	2400	13.66
3	1000-1500	Moderately Suitable	3	909	5.17
4	1500-2000	Suitable	4	218	1.24
5	>2000	Highly Suitable	5	71	0.4
Total				**17574**	**100**

The figures in table 3.10 present that approximately 0.4% of the total areas is categorized as highly suitable , whereas 79.5% is considered unsuitable for waste disposal sites. Additionally, 13.6% is categorized as least suitable, 5.2% as moderately suitable, and 1.2% as suitable for solid waste disposal sites location.

3.4.9 Land Use land cover

Land use Land Cover (LULC) takes crucial role while selecting appropriate sites for solid waste disposal location. Because of fast population increase and limited land availability, urban areas necessitate a deliberate process to waste disposal site selection. To promote sustainable urban development, various criteria are assessed, including environmental, social and technological consideration. Improper site location may lead to contamination of available resources such as soil and water , resulting in adverse effects on local

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 126-168 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

ecosystem and public health (Molla, 2024; Yadav et al., 2019). Land cover of the study area was analysed using Santinel-2A data obtained in 2023. The image was georeferenced to the World Geodetic System 1984 (WGS84), and projected into the Universal Transverse Mercator (UTM) Zone 42N grid. The classified pixels were grouped into six (6) categories: water bodies, forest areas, agricultural land, Built-up areas, bare land/rocky lands, and grassland/rangelands, as presented in figure 15 below.

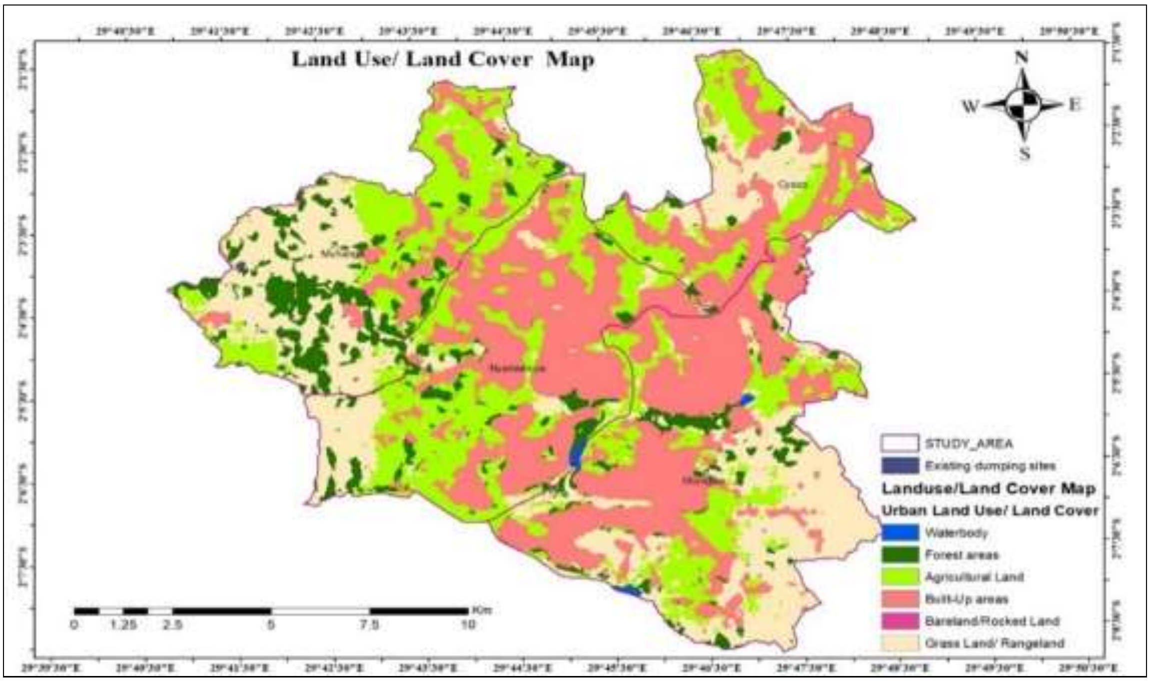

Figure *3*:22. Land Use/Land Cover in the study area

Solid waste disposal should be located faraway of water bodies, residential area, and protected areas to prevent potential conflicts (Kumar et al., 2024). As noted by Abdel-Razzaq et al. (2024) and Dwivedi et al (2024), area with low vegetation density, gentle slope and suitable soil types are more suitable for solid waste disposal sites location. Based on these factors, land use types were classified to identify optimal location for solid waste disposal within the study area. Grassland/Rangelands were ranked as highly suitable, forest areas as suitable, agricultural areas ranked as moderately suitable, Rocklands as least suitable, and areas nearby built-up zones and water bodies as unsuitable for solid waste disposal site location. Based on land use and land cover data presented in table 3.11 and figure 3.22, highly suitable area account for 26%, while moderately suitable areas cover 28%. Additionally, 9% of total area is categorized as suitable, whereas 37 % of the study area has been classified as unsuitable for solid waste disposal site location.

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 126-168 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

Table *3*:9. Land/Land cover Suitability in the study area

Sno	Land/land cover types	Level of Suitability	Ranks	Area (ha)	(%)
1	Buit-up/water bodies	Unsuitable	1	3925	37.0
2	Rangeland/grassland	Highly suitable	5	2747	26.0
3	Agriculture	Moderately suitable	3	2998	28.0
4	Forest area	Suitable	4	900	9.0
5	Bareland/ rocky land	Least Suitable	2	8	0
Total				**10578**	**100**

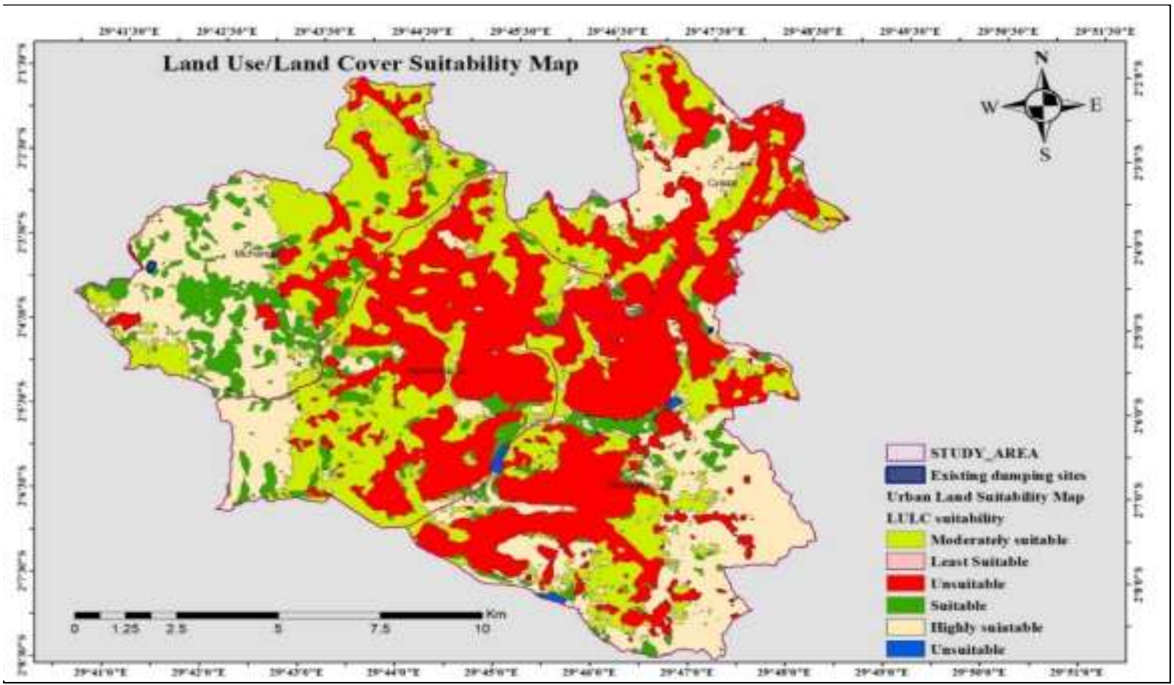

Figure 30:23. Land/ Land cover suitability Map

3.5 Optimal solid waste disposal site thematic map

3.5.1 Assigning criteria weights and overlaying identified suitable sites

The weighting criteria being an important part of the GIS-Based Multi-Criteria Evaluation (MCE) methodology. The aim of weighting in waste disposal site location process is to indicate the relative importance or preference of each criterion in identifying site suitability. The multi-criteria decision-making literature highlights a variety of ways for calculating criterion weights, including ranking, rating, and pairwise comparison. These techniques vary in terms of accuracy, usability, and theoretical foundation (Aziz, 2022; Ouma et al., 2011). The selection of a solid waste disposal site involves evaluating multiple criteria by considering their environmental, social, and economic impacts. Based on the potential effects on the surrounding environment, different criteria were assigned varying levels of influence. Higher weights indicate greater influence in the overall assessment. These

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 126-168 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

weighting process determined based on a series of pairwise comparisons, assessing the relative importance of each factor in determining the suitability of specific locations. The weighting process followed the Analytical Hierarchy Process (AHP) framework developed by Saaty (1980). Weights are calculated in AHP by determining the primary eigenvector of a square reciprocal matrix produced by pairwise criterion comparisons. These comparisons evaluate the relative relevance of two criteria at a time in assessing appropriateness for the defined goal. To create the pairwise comparison matrix, all feasible criteria combinations were examined using expert opinion. The model uses this matrix to generate a set of weights as well as a consistency ratio, which is critical for recognizing any discrepancies that may have happened throughout the comparison process. The weight values assigned using a pairwise comparison method based on a 9-points continuous scale (**table 3.12**).

Lawal et al. (2011) defined an appropriate reciprocal matrices as having a consistency ratio of 0.1 or below. In this analysis, the consistency ratio was determined to be 0.04, which was considered acceptable. In order to combine all layers for overlay analysis, each dataset was standardized to a similar scale of 1 to 5, with 1 representing unsuitable, 2 indicating least suitable, 3 indicating moderately suitable, 4 suitable, and 5 indicating highly suitable. Therefore, pairwise comparison were analysed to generate eigenvectors for all waste site selection parameters that collectively add to one (1.0), as shown in **table 10** below.

Table *3*:10 Factors and their eigenvectors weights for solid waste disposal site location in the satellite city of Mukanga

Criteria	Bt-u	LULC	Rd	R/S	Wt	S	Sl	PA	El	Eigenvector weights	%
Bt-u	1	1	1	2	2	2	3	4	4	0.193	19
LULC	1	1	1	2	2	2	1	2	2	0.148	15
Rd	1	1	1	3	2	2	2	1	1	0.152	15
R/S	1/2	½	1/3	1	1	2	2	1	2	0.099	10
Wt	1/2	½	1/2	1	1	2	2	1	2	0.102	10
S	1/2	½	1/2	1/2	1/2	1	1	2	2	0.082	8
Sl	1/3	1	1/2	1/2	1/2	1	1	2	2	0.087	9
PA	1/4	1/2	1	1	1	1/2	1/2	1	2	0.079	8
El	1/4	1/2	1	1/2	1/2	1/2	1/2	1/2	1	0.059	6
Total	**5.3**	**6.5**	**6.8**	**11.5**	**10.5**	**13**	**13**	**13.5**	**18**	**1**	**100**

CI=0.066 **RCI**=1.45 **Consistency Ratio** (**CR**=0.0453) < 0.1 (Acceptable)

Where **Bt-u**- Built -up **LULC-** Land Use Land Cover **Rd-** Roads **R/S-** rivers/ streams **Wt-** Wetlands **S-** Soil **Sl-** Slope **PA-** Protected Area **El-** Elevation; and **CI-** consistency Index, **RCI-** Random Consistency Index.

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 126-168 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

Factor weights were derived using a pairwise comparison Matrix, which compares two criteria at a time on a scale of 1/4 to 3. A rating of 1/4 means that the column criterion is less essential than the row factor, whereas a value of 4 shows that the row element is more important in comparison. When both criteria have equal value, they are given a rating of one (1.0). For example, when we see an intensity of importance rating of 2, it shows that one criteria is equal to moderately importance over other being compared, whilst a rating of 4 suggests a moderately to strongly more importance over the compared criterion. Moreover, the higher weight, the more influence that a given input might has in the suitability model (table 3.11).

Table *3*:11 Weight of suitable solid Waste disposal site selection Factors

N.0	Factor	Criteria value	Value	Suitability classes	Influence
1	Soil types	Clay	5	Highly suitable	8%
		Sandy loam	3	Moderately Suitable	
		Sandy clay loam	2	Least suitable	
		Clay loam	4	suitable	
2	Slope	0-5%	2	Least Suitable	9%
		5-10%	5	High suitable	
		10-15%	4	Suitable	
		15-30%	3	Moderately suitable	
		>30%	1	Unsuitable	
3	Altitude	<1700m	5	Highly suitable	6%
		1700-1800m	4	suitable	
		1800-1900m	3	moderately suitable	
		1900-2000m	2	least suitable	
		>2000m	1	Unsuitable	
4	Road Network	>1500m	2	Least suitable	15%
		200-500m	3	Moderately suitable	
		1000-1500m	4	Suitable	
		500-1000m	5	Highly Suitable	
		0-200m	1	Unsuitable	
5	Rivers/stream	0-200m	1	Unsuitable	10%
		200-500m	2	Least suitable	
		500-1000m	3	Moderately Suitable	
		1000-1500m	4	Suitable	
6	Built-up areas	0-200 m	1	Unsuitable	19%
		200-500 m	2	Least suitable	
		500-1000 m	3	Moderately suitable	
		1000-1500 m	4	Suitable	
		>1500m	5	Highly suitable	
7	Protected area	0-500m	1	Unsuitable	8%
		500-1000m	2	Least Suitable	
		1000-1500m	3	Moderately Suitable	

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Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 126-168 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

N.0	Factor	Criteria value	Value	Suitability classes	Influence
		1500-2000m	4	Suitable	
		>2000m	5	Highly Suitable	
		0-500	1	Unsuitable	
		500-1000	2	Least Suitable	
8	Wetlands areas	1000-1500	3	Moderately Suitable	10%
		1500-2000	4	Suitable	
		>2000	5	Highly Suitable	
		Buit-up/water bodies	1	Unsuitable	
		Rangeland/grassland	5	Highly suitable	
9	LULC	Agriculture	3	Moderately suitable	15%
		Forest area	4	Suitable	
		Bare land/ rocky land	2	Least Suitable	

3.5.2 Solid waste dumping site suitability Results

The influence of environmental criteria such as hydrological factors like proximity to streams, rivers, and wetland along with topographic factors such as slope and land use, as well as the distance to residential areas and road networks, vary when identifying suitable location for solid waste dumping sites. The weight analysis indicates that proximity to built-up areas, Land use land cover (LULC), proximity to roads, and environmental factors such as distances to rivers, streams, and wetlands, along with topographical factor like slope, have a significant influence (Table 3.14). The Weighted Linear Combination analysis showed suitability into four categories: unsuitable, moderately suitable, moderately suitable, and suitable. The total results show that no location fits the requirements for highly suitable areas, implying that none of the analysed area portions fully satisfy all nine (9) criteria. The area coverage for each suitability class was calculated using a GIS environment after converting the raster data to vector format. The analysis found that 33 hectares (0.3%) of the study area is completely unsuitable for solid waste disposal site owing to environmental, social, and economic considerations. The unsuitable area include densely populated areas and water bodies, position closer to roads, steep slope (>30%), and area nearby river/stream. The major purpose of these limits is to protect human health and the environment while reducing construction and waste transportation expenses.

Moreover, no identified area within the study area meets the environmental, social, and economic criteria, making it less suitable for selecting a solid waste disposal site. This may attributed to densely populated, hilly terrain characterized by high and low peaks. These conditions increase the risks of erosion and leakage contamination during rainfall, in addition to challenge associated to waste containment on sloped land. In contrast, 6922 hectares (67%) of the study area is considered least suitable. These areas can be used as dumping sites, but with rigorous conditions to minimize environmental and social risks. Environmental protection methods such as buffer zones, erosion control, and runoff management are essential for preventing pollution and biodiversity loss. Social and health considerations must also be addressed, including keeping a safe distance from settlements, engaging local communities, and ensuring protection of workers. Additionally, suitable operational methods such as waste segregation, frequent monitoring, and a well-planned site rehabilitation procedure should be used. While these methods can help to mitigate negative consequences, choosing a more suitable alternate location is still the best option. An area of 3217 hectares (31%) is classified as moderately suitable, while 175 ha (1.7%) considered as suitable for the location of solid waste disposal sites (table 3.15). Yet, numerous conditions must be fulfilled whilst locating dumps in moderately or suitable places in order to address environmental and social challenges. Effective control of ground and surface-level pollution, appropriate leachate management, impermeable liners, along with appropriate drainage systems are required. Security measures, such as fencing and restricted access, should be provided to prevent illegal dumping. Furthermore, compliance with environmental requirements, such as undertaking an Environmental Impact Assessment (EIA) and frequent monitoring, is required to ensure sustainable waste management.

Table *3*:12 Level of Suitability and Percentage of total area coverage in the study area

No	Level of suitability	Ranks	Area(ha)	%
1	Unsuitable	1	32	0.3
2	Moderately Suitable	3	3217	31.1
3	Least Suitable	2	6922	66.9
4	Suitable	4	175	1.7
Total			**10346**	**100.0**

Depending on the factors used, the best site for solid waste disposal might make transportation easier and save money. Furthermore, a slope analysis found that locations between 5-10% slope category are optimum for lowering environmental impact. The optimal location is primarily grasslands/rangelands, away from rivers, marshes, and built-up regions. Figure 3.23 shows shows that the acceptable solid waste disposal site is located in the western and southeast areas of the satellite city of Muhanga.

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 126-168 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

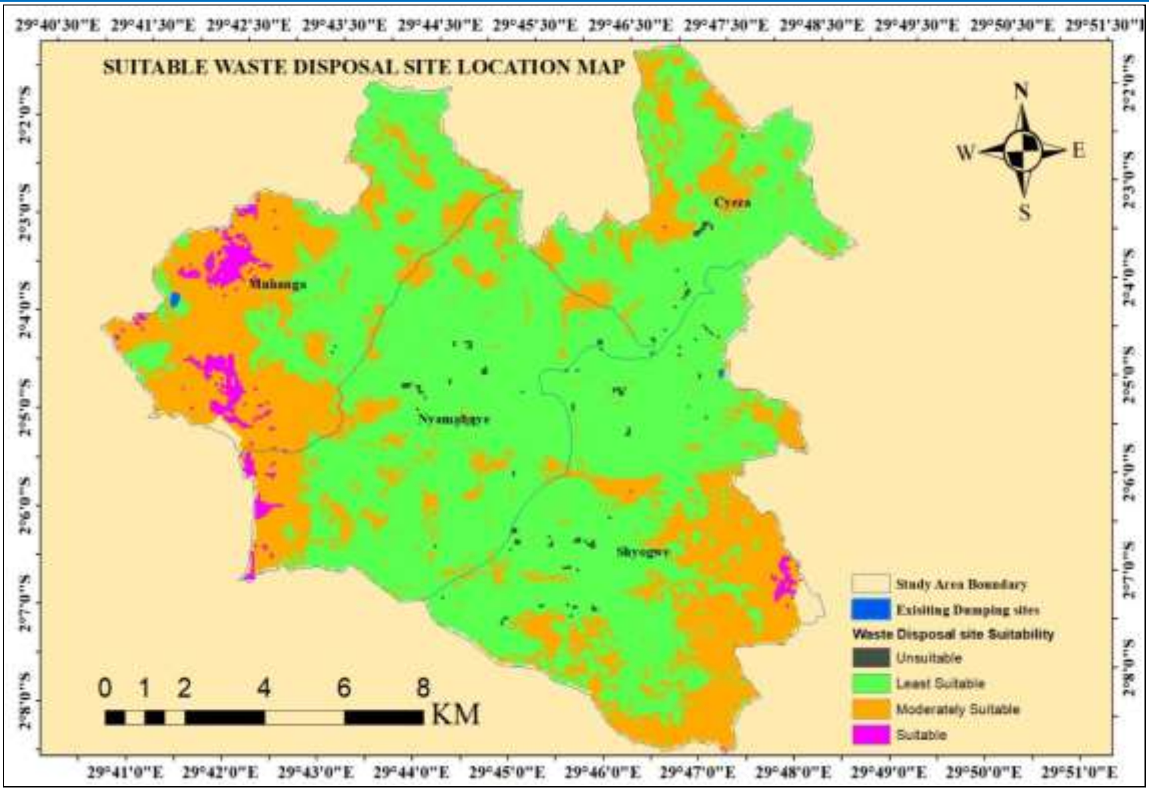

Figure *3*:24 Solid Waste disposal Suitability Map

Figure 3.24 depicts the moderate and suitable classes for suitability location of solid waste disposal sites in relation residential areas, rivers/streams, and wetlands, as well as road networks. As shown, the most optimal dump sites are at adequate distance from roadways, rivers and streams as well from residential areas and surface waters like rivers and streams. There areas are mainly in grasslands spaces.

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 126-168 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

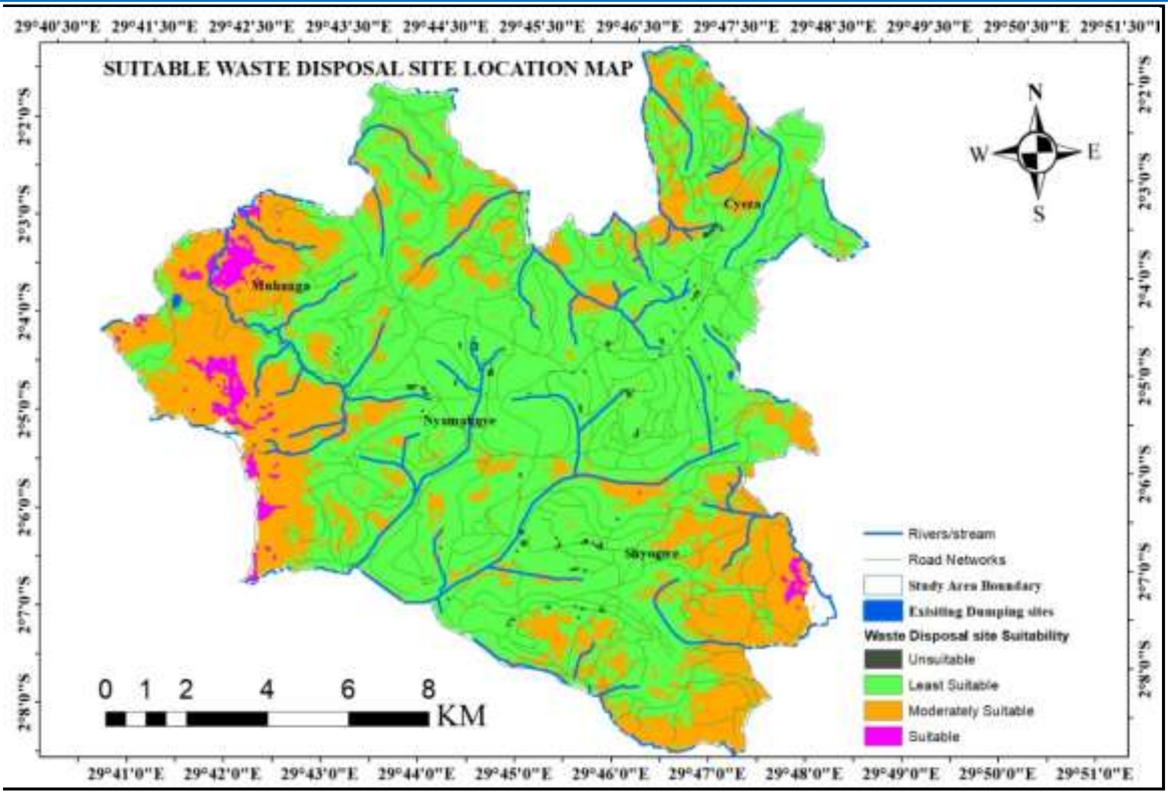

Figure *3*:25 Overall Solid Waste disposal site suitability Map in satellite city of Muhanga

4. Results Discussions

Open dumping sites present major environmental and public health threats, contributing to air pollution, water contamination, soil degradation, and greenhouse gas emissions, as seen in Dandora (Kenya) and Olusosun (Nigeria) (Omokaro et al., 2024; Siddiqua et al., 2022; Yadav et al., 2019). Communities near dumpsites face heightened risks of disease transmission and exposure to heavy metals like lead and cadmium (Adamu & Audu, 2020; Adamu, 2019). A weighted overlay analysis in Muhanga satellite city classified land into unsuitable, least suitable, moderately suitable, and suitable categories, with only 1.7% considered suitable for waste disposal. Key suitability factors included proximity to urban centers, roads, and sensitive environments, aligning with findings from Mussa & Suryabhagavan (2021), Kebede & Ayenew (2023), and Ouma et al. (2011). Rapid urbanization exacerbates challenges by increasing waste volumes faster than facility development (Kaza et al., 2018). Similar GIS and AHP-based approaches have been applied globally in Ethiopia, India, and Peru (Abdel-Razzaq et al., 2024; Chandel et al., 2024b; Gebremedhin et al., 2023; Kumar et al., 2025; Nwosu & Pepple, 2016). Inappropriate disposal sites near wetlands in Muhanga echo findings by Zhang et al. (2024) and Abubakar et al. (2022) on urban water quality degradation. Strengthening regulations, adopting GIS-AHP tools, promoting recycling, and enhancing community involvement, as suggested by Abdulwaheed et al. (2024) and Ferronato & Torretta (2019), are essential for sustainable waste management in Muhanga.

5. Conclusion

In conclusion, this study assessed solid waste disposal practices and suitable site selection in Muhanga Satellite City, Rwanda. Findings revealed that the current waste management system is inadequate, characterized by widespread open dumping near residential areas, water bodies, and roads, leading to significant environmental and health risks. Using GIS and AHP methods, 9 key criteria were identified, with proximity to settlements and water resources being the most influential. The spatial analysis showed that only 1.7% of the area was suitable for waste disposal, with most of the land being least suitable or unsuitable. Environmental impact assessments confirmed that uncontrolled dumping results in pollution, biodiversity loss, and public health issues. The study concludes that GIS and AHP are effective tools for informed waste management planning. Urgent interventions are needed, including improved infrastructure, stricter regulation, public engagement, and investment in sustainable waste treatment technologies to mitigate environmental degradation and protect public health.

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Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 126-168 ||April||2025|
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