International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 06 June 2024, pp: 869-877 www.ijaem.net ISSN: 2395-5252

Potential suitable sites for housing development in the secondary cities of Rwanda, a case of Musanze district

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Date of Submission: 15-06-2024 Date of Acceptance: 25-06-2024

ABSTRACT
Housing development is crucial for secondary cities to accommodate rapid urbanization. However, selecting appropriate sites for new housing is challenging due to multiple criteria including land availability, infrastructure access, environmental impacts, and costs. Thus, this study aims to use geographic information systems (GIS)-based multicriteria evaluation to identify and prioritize suitable sites for housing development in the Musanze district of Rwanda. The criteria for site suitability included factors like slope, land use/land cover, proximity to roads, elevation, and soil types approximately. The researcher was employing secondary data on potential suitable sites for future housing development data needed consist of satellite imagery (Landsat and digital elevation model at 30m spatial resolution), and administrative boundary (Shapefile's) of Musanze. GIS layers quantifying these criteria were created, weighted based on stakeholder input, and combined into a suitability map indicating locations best suited for housing development. The goal was to provide an objective, spatially explicit decision support tool for planning agencies to facilitate informed site selection and sustainable urban growth in Musanze. The results indicated candidate areas suitable for housing development within Musanze City. Accordingly, the 'Most suitable class contributes about 3602.50 ha (27.98 %), whereas, the 'Suitable' class accounted for about 4238.60 ha (32.92%). Meanwhile, under the class of 'Less suitable' there is potential for about 4765.43 ha (37.01 %) of additional land to be used for housing development. However, about 268.15ha (2.08%) of land have been classified as 'Not suitability a (2.08%), are currently 'unsuitable' for housing development purposes. The GIS-based Multicriteria Evaluation technique provides a powerful tool for identifying potentially suitable sites for housing development in Musanze district, Rwanda. By integrating spatial data and criteria analysis, this approach will enable informed decision-making, promote sustainable development, and enhance the quality of life for residents. Musanze City continues to grow and evolve, and leveraging such methodologies was essential for shaping its urban landscape in a manner that is both equitable and environmentally responsible. The proposed methodological framework can also be replicable in other locations following the countries' national master plan.

I. INTRODUCTION

House development can be defined as an increase in the general population of any urban area and it is one of the changes happening in the world today [1]. House development plays a very important aspect in any city as regards the environment, economy, and social life. One of the major causes of house development is the movement of people from rural areas to urban areas in search of better life and job opportunities due to the rise in industrialization. The goal of housing development is to provide safe, comfortable, and sustainable living spaces that contribute to the quality of life and wellbeing of residents while fostering community cohesion and economic growth. Utilizing Geographic Information System (GIS) mapping tools in conjunction with the Analytic Hierarchy Process (AHP), developers can systematically evaluate numerous potential sites for housing development, considering factors like proximity to amenities, infrastructure availability, environmental considerations, and market demand [3].GIS allows for spatial analysis to assess various criteria, while AHP facilitates the prioritization of these criteria based on their relative importance through pairwise comparisons .The unplanned and uncontrolled rapid growth has resulted in serious negative effects on the suburban dwellers and their environment [4]. Therefore, much attention has been paid to addressing the issue of urbanization and its negative impact on the socio-economic and environment. Sustainability should be practiced by

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both developed and developing countries. Urbanization is not a problem of its own when the drastic increase in urban population occurs especially in countries that lack the resources and personnel to deal with it. Rwanda is a small and landlocked country with a precise size of 26,388 km2 and is very hilly, without proper planning the future generation is in danger of the scarcity of this land [5].The population of Rwanda increases each year at a rate of approximately 3% and now in June 2022 the Rwandan population is 13 million and we are still counting every day. As World Meter says, the size mentioned above includes lakes, rivers, land, and swamps, now the total land area is 24,670 km^2 which will have to be cultivated on, built upon, sustain forests for environment conservation, and provide all other human needs like cemeteries, parks, military camps, etc. Musanze is a district in the Northern Province of Rwanda. Its capital city is Ruhengeri, Musanze is the fourth largest town in Rwanda with a total area of 530 km^2 quickly growing into a busy and most important city in the country with high potential for urban development after Kigali, the capital city of Rwanda [6].

II. METHODOLOGY

2.1. Study area description Musanze city is located in Musanze District in the Northern Province of Rwanda. It is one of the five Districts within the Northern Province, located between $1^0 29' 30.8''$S, $1^0 30' 21.9''$S parallels and between $29^0 33' 25''$E, $29^0 32' 45.5''$ 'E meridians. Musanze District covers the areas of 530.4 km^2, including 60 km^2 that is covered by the Volcanoes National Park and 28 km^2 that are covered by Lake Ruhondo.It is bordered by Nyabihu District in the West, Burera District in the East, Uganda and Democratic Republic of Congo (D.R.C) in the North, and Gakenke District in the South. The study was carried out within Musanze City which comprises five sectors: Cyuve, Musanze, Muhoza, Muko, and Kimonyi, and covers a total area of 128.9367 km², Musanze City is one of the largest and fastgrowing urban centers in Rwanda. It is a central hub for businesses, trade, and tourism [7].

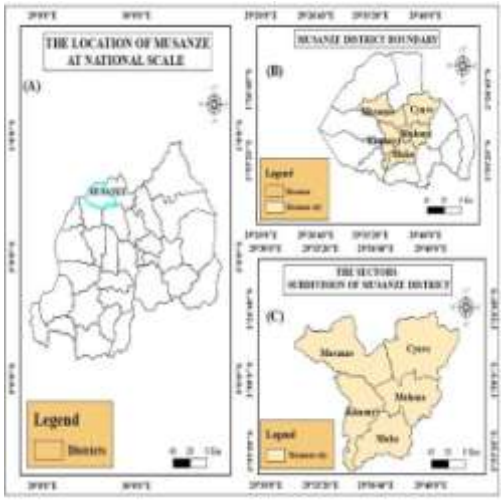

Figure 1: Map of the Study Area

2.3. Data Collection and analysis

The needed dataset was consisting of different remote sensing satellite images including the Landsat images and digital elevation model (DEM). Moreover, the administrative boundaries (shape files) of the study area were also be of great significance the remote sensing datasets was acquired from the Earth Resources Observation System (EROS) Data Centre of the U.S.G.S (United States Geological Survey) as it is cost-effective free of charges).To achieve this research was using secondary data, from the existing literature to different spatial datasets collected from various sources, data used in this study were secondary data such as Landsat 8 OLI of August 2019 image with 30 m of resolution was used for determining Land use/ Land cover classification of a study area. The image used in this study was downloaded from the United States Geological Survey (USGS), While, Rwanda Administrative shapefiles was used for producing the division of ad ministrative map of the study area from Rwanda geo portal, Digital Elevation Model (DEM) 12.5cm were downloaded from Vertex.daac.asf.alaska.edu used for producing slope ad elevation, and aspect map all dataset were processed and reclassified for determining future housing development suitability area map [8].

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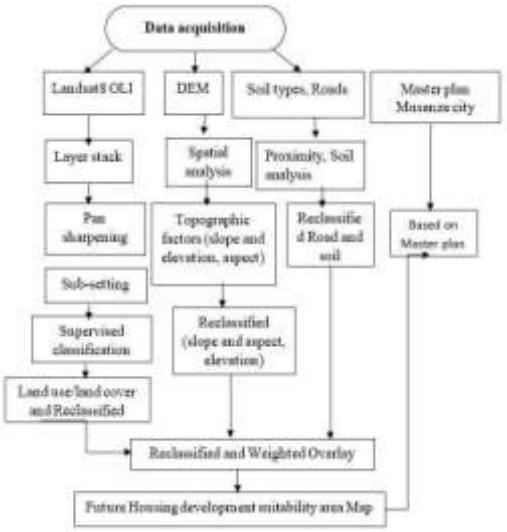

Figure 2: Methodological Framework

The input data layers required for the multicriteria evaluation of housing development suitability was derived from a variety of sources. This research was used secondary data from the existing literature to different spatial datasets collected from various sources, data used in this study were secondary data such as Landsat 8 OLI of August 2019 image with 30 m of resolution was used for determining Land use/ Land cover classification of a study area. The image used in this study was downloaded from the United States Geological Survey (USGS), While, Rwanda Administrative shapefiles was used for producing the division of administrative map of the study are from Rwanda geoportal, Digital Elevation M odel (DEM) 12.5cm were downloaded from Ve rtex.daac.asf.alaska.edu used for producing slope ad elevation, and aspect map all dataset were processed and reclassified for determining future housing development suitability area map. **3.3. Results**

2.3.1. Criteria for locational suitability for residential development

In this study., six criteria were considered. The principal criteria that are used for the spatial analysis were elevation, slope, aspect, land use/cover, soil types and proximity to roads. These criteria were integrated in ArcGIS applying a weighted overlay techniques for housing suitability mapping.

2.3.2. Elevation

In line with the elevation of the area, the results of this study, the none suitable covered 12.47 %, less suitable by 21.98 %, suitable by 41.13 % and most suitable occupy 24.42 % of Musanze city for whole area respectively.Elevation significantly influences the suitability of house sites for future construction in Musanze city. Higher elevations may offer panoramic views of the surrounding landscape, cooler temperatures, and reduced flood risk, but they may also present challenges such as limited accessibility, increased exposure to wind, and higher construction costs due to site preparation and infrastructure requirements [8]. Additionally, higher elevations may be subject to stricter building regulations, particularly regarding slope stability and environmental conservation . Lower elevations like 1640-1784.94 m were considered as most suitability for housing.

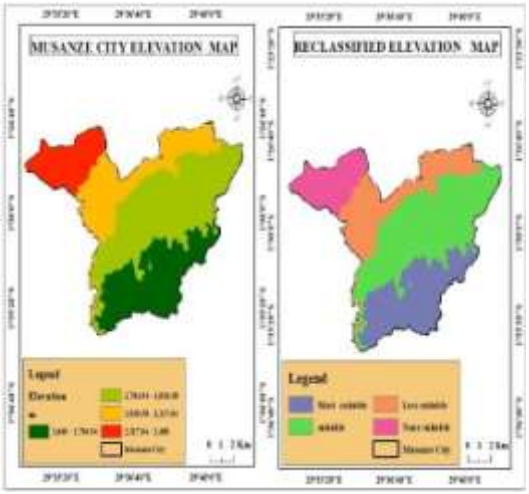

Figure 2. Elevation of Musanze city map

2.3.3. Slope

In line with the slope of the area, the results of this study, the none suitable covered 4.14 %, less suitable by 8.55 %, suitable by 35.72 % and most suitable occupy 51.59 % of Musanze city for whole area respectively.Generally, the slope of the land plays a crucial role in determining the suitability of a site for future house construction. Steep slopes present challenges such as soil erosion, stability issues, and increased construction costs due to the need for specialized foundation and retaining wall structures. As far as the topography of the study area is concerned, since the steeper slope demands relatively gentle slopes with flat terrain were much preferable. Contrary, steep slope area eventually increased cost of construction. Thus, an area with slope between 2% -15 % is suitable for housing. Additionally, steep slopes may limit the usable space for building and outdoor activities and pose safety concerns, especially during heavy rainfall or seismic events. On the other hand, gentle slopes offer advantages such as

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natural drainage, scenic views, and easier construction. Proper site evaluation, including slope analysis and soil stability assessments, is essential to identify suitable locations for house construction in Musanze city, ensuring safety, functionality, and environmental sustainability for future residents [9].

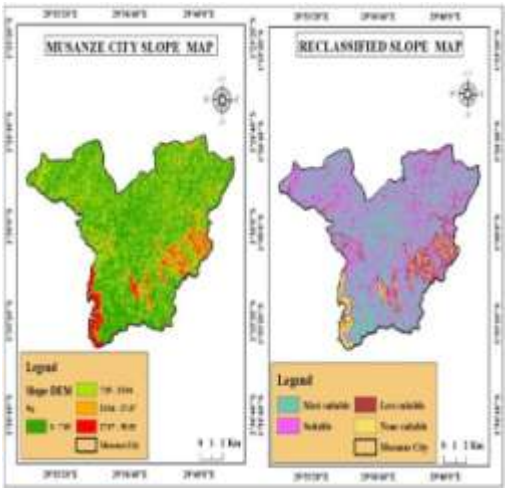

Figure 3. Slope of Musanze city map 3.3.4. Aspect

Aspect generally refers to the horizontal direction to which a mountain slope faces. Aspect identifies the steepest down slope direction from each cell to its neighbors, where, the value of the output raster data set represents the compass direction. The aspect chosen for mapping housing suitability typically reflects the priorities and objectives of the mapping project, as well as the needs of the target population slope orientation can impact erosion rates, soil moisture levels, and microclimatic conditions, all of which influence land use practices and land cover dynamics. Therefore, in our LULC classification analysis, we will consider the orientation of slopes as a key factor in understanding and interpreting landscape patterns and processes within our study area. Ultimately, the chosen aspect serves as a guiding framework for assessing the suitability of housing locations based on specific criteria relevant to the context and goals of the mapping initiative. Hence, the eastern and western direction was considered to be more suitable means that in interpreting slope orientation within the context of land use and land cover (LULC) classification, certain directions may hold more significance than others due to their implications for environmental conditions and human activities. For instance, south-facing slopes in the northern hemisphere typically receive more sunlight throughout the day, making them more conducive to vegetation growth and agriculture. Conversely, north facing slopes may experience cooler temperatures and higher moisture levels, influencing vegetation composition and land use practices such as forestry [10]. East-facing slopes receive sunlight in the morning, while west-facing slopes receive it in the afternoon, affecting temperature regimes and potential land use activities such as vineyard cultivation or solar energy generation.

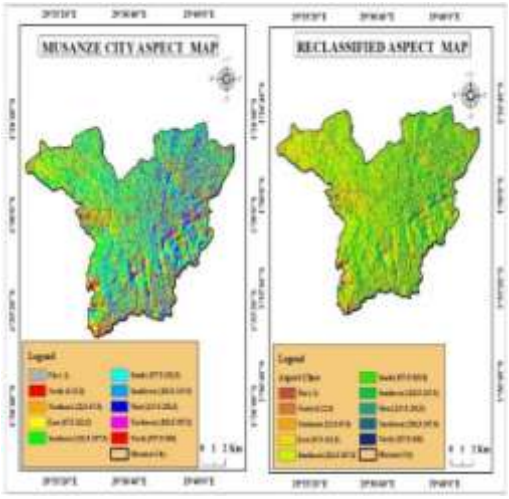

Figure 4. Aspect of Musanze city map 3.3.5. Land-uses/land-cover the results of this study show that bare soil occupies 13.99 %, built-up cover 14.48% and open land occupy 65% of Musanze city whole area with high suitability is agriculture cover 65 % and Forest occupies 6.41 % respectively.the LULC has been classified as follows: Vegetation, Built-up, Urban Forest, and bare soil. In this study, built-up area is restricted (unsuitable) since it is already developed area, whereas, bare land is given high preference followed by construction land for new housing development. The land use and land cover characteristics of Musanze city play a crucial role in determining the suitability of sites for future house construction. Areas designated for agricultural use may have fertile soils but could be subject to land use restrictions or conflicts with farming activities. Urbanized areas may offer convenient access to infrastructure and services but may also face higher land prices and limited availability [11]. Natural areas, such as forests or wetlands, provide important ecosystem services but require careful conservation and may be subject to environmental regulations. Therefore, understanding the existing land use patterns and land cover types is essential for identifying suitable house sites, balancing the needs of development with environmental

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conservation, and promoting sustainable growth in Musanze City for future residents.

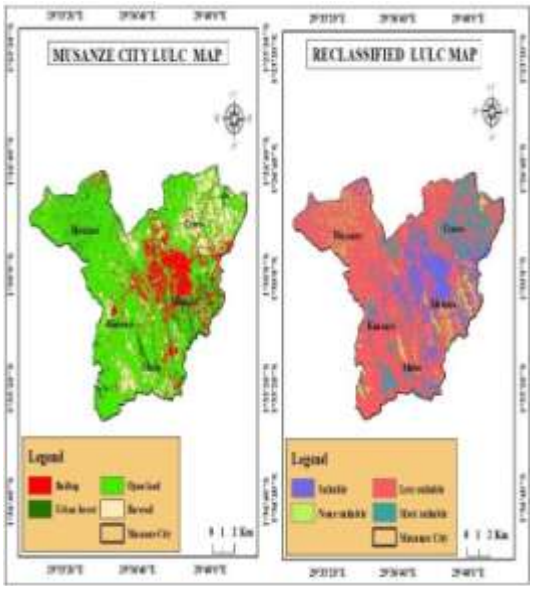

Figure 5. Land use land cover of Musanze city

2.3.6. Soil properties

In line with the soil types of the area, the results of this study, the none suitable covered 48.36%, less suitable by 7.38 %, suitable by 22.72% and most suitable occupy 21.54% of Musanze city for whole area respectively.In Musanze city, the diverse topography gives rise to various soil types, each with its implications for house suitability. Volcanic soils, enriched by the nearby Virunga Mountains, offer fertility but may require erosion control measures. Lateritic, common in mountainous regions, are shallow and may limit foundation depth but can support lighter structures. Andosols, derived from volcanic ash, are fertile but prone to erosion. Humas bearing soil, typical of tropical climates, vary in fertility and drainage and require careful assessment. Vertisols, with their moistureinduced volume changes, demand careful foundation design. Podzols, while well-drained, are acidic and may need amendments for landscaping. A thorough soil survey and geotechnical investigation are essential to understand the site-specific challenges and ensure appropriate construction practices in Musanze City's diverse soil landscape. Thus, the soil properties classes were reclassified based on their properties and suitability for housing development [12].

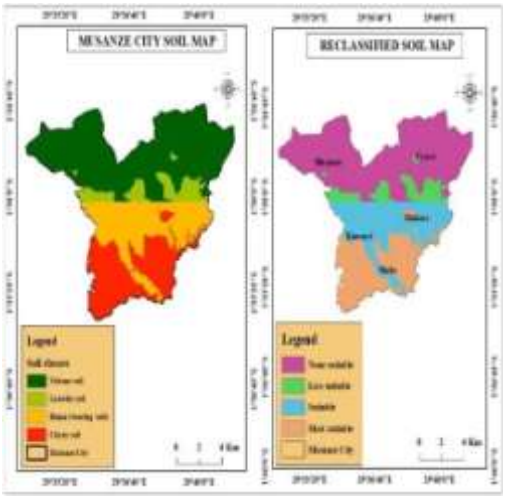

Figure 6. Soil types of Musanze city map

2.3.7. Proximity to roads analysis Generally, Proximity to roads is a critical factor influencing the suitability of sites for future house construction. Houses located close to well-maintained roads typically offer convenient access to transportation networks especially 50m from to roads network were considered as most suitability to housing, facilitating daily commuting, access to amenities, and emergency services.

Additionally, proximity to roads can enhance property value and marketability. However, houses located too close to busy roads may experience noise pollution, safety concerns, and reduced privacy. Moreover, the type and condition of roads, as well as potential future road development projects, should be considered to assess the long-term suitability of house sites. Therefore, conducting a thorough analysis of proximity to roads is essential to ensure the optimal balance between accessibility, comfort, and quality of life for future residents in Musanze city. The infrastructure like road network were considered in this research in order to identify suitable site for housing for future in Musanze was all; road which located in Musanze city. The results of study on infrastructure to identify potential site for housing for the future, after multi-buffer method for infrastructure according to (Suleman and Baffoe,2017) the suitable distance for settlement area, shows that the Most suitable area in 50m from road network of whole area of study area respectively [13].

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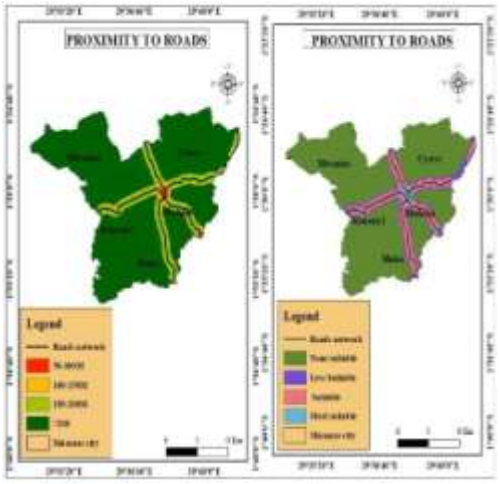

Figure 7. Proximity roads analysis 3.4. Site suitability analysis

Site suitability analysis using the Analytic Hierarchy Process (AHP) involves evaluating and prioritizing different factors that influence site selection. AHP is a decision-making method that helps to quantify subjective judgments in a systematic manner. The process involves breaking down the problem into a hierarchy of criteria and alternatives, and then comparing these factors based on their relative importance and performance against each other. By assigning numerical values to these factors, AHP allows for a comprehensive analysis of multiple criteria, such as accessibility, infrastructure, environmental impact, and economic viability. This approach enables decision-makers to make informed choices based on objective evaluations of various factors influencing site suitability [14].

Table 1. Pairwise comparison matrix, normalized pairwise comparison matrix and computation of criterion weights

Criteria	Slope	Elevation	Proximity to Road	LULC	Soil types	Aspect
Slope	1	3	4	6	8	9
Elevation	1/3	1	3	4	6	8
Proximity to Road	1/4	1/4	1	3	4	6
LULC	1/6	1/6	1/6	1	3	4
Soil types	1/8	1/8	1/8	1/4	1	3
Aspect	1/9	1/9	1/9	1/6	1/4	1
Total	1.975	4.64	8.39	14.4	22.25	31

Table 2. Pairwise comparison matrix

Criteria	Slope	Elevation	Proximity to Road	LULC	Soil types	Aspect
Slope	1	3	4	6	8	9
Elevation	1/3	1	3	4	6	8
Proximity to Road	1/4	1/4	1	3	4	6
LULC	1/6	1/6	1/6	1	3	4
Soil types	1/8	1/8	1/8	1/4	1	3
Aspect	1/9	1/9	1/9	1/6	1/4	1
Total	1.975	4.64	8.39	14.4	22.25	31

Table 3. Normalized pairwise comparison matrix

Criteria	Slope	Elevation	Proximity to Road	LULC	Soil types	Aspect
Slope	0.51	0.65	0.48	0.42	0.36	0.29
Elevation	0.17	0.22	0.36	0.28	0.27	0.26
Proximity to Road	0.13	0.05	0.12	0.21	0.18	0.19
LULC	0.08	0.03	0.02	0.07	0.13	0.13
Soil types	0.06	0.03	0.01	0.02	0.04	0.10
Aspect	0.06	0.02	0.01	0.01	0.01	0.03
Total	1	1	1	1	1	1

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Table 4. Computation of consistency vector and computation of criterion weights

Total criteria	Criteria	Weighted sum vector	Consistency vector	%
2.70	0.45	2.87	0.45	45
1.55	0.26	1.61	0.26	25.76
0.88	0.15	0.87	0.14	14.69
0.47	0.08	0.44	0.07	7.80
0.26	0.04	0.24	0.04	4.36
0.15	0.02	0.14	0.02	2.45
6	1		1	100

In addition, the weight overlay function with 1 to 5 scales has been executed in model builder tool of spatial analysis tool docked in arc tool box of Arc-Map to identify potential sites for new housing development sites. All 6 criteria maps were converted into raster format, so that for each pixel, a score can be determined. All the criteria maps were integrated and overlaid and the final site suitability map (figure 3) was prepared by the following formula: Suitability map= Σ [Criteria Map * Weight] Suitability map = ([reclassed slope] * 47.45) + ([reclassed land-use] * 7.39) + ([re-classed road] * 14.65) ([re-classed elevation * 26.94) + ([re-classed soil types* 4.010) + ([reclassed Aspect] * 2.36).

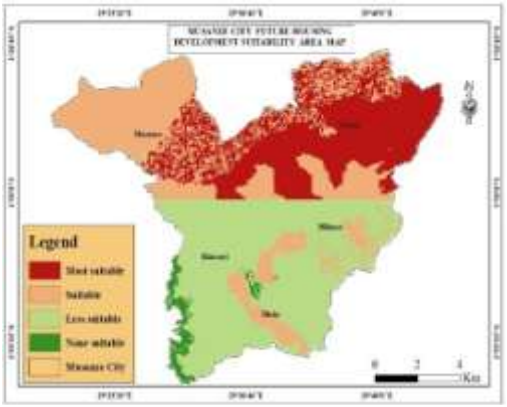

Figure 8. Musanze city future housing development suitability map

The results of the study have revealed that the most significant factor contributing to the suitability of housing development within Musanze city is the slope, elevation, aspect, soil properties, LULC, proximity to roads. Among all the factors considered. This suggests that the topographical characteristics of the land play a crucial role in determining its suitability for housing development in Musanze. The findings underscore the importance of considering slope gradients in urban planning and development strategies to ensure sustainable and suitable housing expansion within the city. Accordingly, to the future housing development suitability map were indicated that most suitable class contributes about 3602.50ha (27.98 %), whereas, 'Suitable' class accounts for about 4238.60 (32.92%). Meanwhile, under the class of 'Less suitable' there is potential for about 4765.43 (37.01 %) additional land to be used into housing development. However, about 268.15 (2.08%) land have been classified as 'None suitability was a (2.08%), are currently 'unsuitable' for housing development purpose [15].

Table 5. Area in ha and % of future housing development suitability area

Class	Area in Ha	%
Most suitable	3602.50	27.98
Suitable	4238.60	32.92
Less suitable	4765.43	37.01
None suitable	268.15	2.08
Total	12874.69	100

2.4.1. Challenges limiting housing development in identified high-potential residential zones

Assessing challenges limiting housing development in identified high-potential residential zones requires a comprehensive understanding of various factors spanning economic, social, environmental, and regulatory domains. One significant challenge is the cost of land acquisition and development. In high potential residential zones, land prices tend to be inflated due to high demand, speculation, or scarcity of available land, posing a significant barrier to entry for developers.

Additionally, zoning regulations and land use policies may restrict the type and density of housing that can be built, further limiting the potential for development [16]. Infrastructure deficiencies represent another major challenge. Many high potential residential zones may lack adequate infrastructure such as roads, water supply, sewage systems, and utilities necessary to support housing development. The cost of installing or upgrading these infrastructures can be prohibitively high and may require coordination between multiple stakeholders, including government agencies, utility providers, and developers.Access to financing is yet another challenge. Securing funding for large-scale housing projects in high-potential zones can be challenging, especially in regions with volatile real estate markets or uncertain economic conditions [17]. Developers may face difficulties obtaining loans or attracting investment, particularly if lenders perceive the project as high-risk or if there is a lack of proven demand for housing in the area. Navigating the regulatory landscape represents a final obstacle. Development projects in high-potential residential zones must comply with a myriad of local, state, and federal regulations governing land use, construction, and environmental protection. Delays or uncertainties in the permitting process can prolong project timelines and increase costs, discouraging developers from investing in these areas [18].

III. DISCUSSION

This study aimed to identify potential suitable sites for housing development in the secondary cities of Rwanda, focusing on Musanze District, utilizing a GIS-based multicriteria approach.

Through a systematic analysis of six key factors namely slope, elevation, aspect, land use/land cover (LULC), soil types, and proximity to roads, the research has provided valuable insights into the factors influencing site suitability for housing development in the region. The findings of this study have highlighted the importance of considering multiple criteria when assessing the suitability of housing development sites. Factors such as slope, proximity to roads, LULC patterns, elevation, soil types, and aspect were identified as crucial determinants in the selection of optimal sites for housing development in Musanze District. The integration of GIS technology has facilitated a comprehensive spatial analysis, enabling a more informed and data-driven decision-making process. Moreover, the prioritization and ranking of these factors based on their relative importance have offered a clear understanding of the most significant contributors to site suitability. The results emphasize the need for a holistic approach that considers environmental, infrastructural, and regulatory aspects to ensure sustainable and resilient housing developments in secondary cities like Musanze. It is evident from the study that the GIS-based multicriteria analysis has provided a robust framework for identifying potential suitable sites for housing development, offering urban planners and policymakers valuable guidance in spatial planning and land management. By harnessing the power of geospatial technologies and multi criteria evaluation, this research contributes to the sustainable urban development goals of Rwanda, promoting efficient land use practices and facilitating the expansion of housing infrastructure in secondary cities. In summary, this study serves as a foundational step towards enhancing the spatial planning and sustainable housing development initiatives in the secondary cities of Rwanda, underscoring the significance of GIS-based analysis in identifying potential suitable housing sites and supporting informed decision-making for urban growth and development.

IV. CONCLUSION

This study aimed to identify potential suitable sites for housing development in the secondary cities of Rwanda, focusing on Musanze District, utilizing a GIS-based multicriteria approach. Through a systematic analysis of six key factors namely slope, elevation, aspect, land use/land cover (LULC), soil types, and proximity to roads, the research has provided valuable insights into the factors influencing site suitability for housing development in the region. The findings of this study have highlighted the importance of considering multiple criteria when assessing the suitability of housing development sites. Factors such as slope, proximity to roads, LULC patterns, elevation, soil types, and aspect were identified as crucial determinants in the selection of optimal sites for housing development in Musanze District. The integration of GIS technology has facilitated a comprehensive spatial analysis, enabling a more informed and data-driven decision-making process. Moreover, the prioritization and ranking of these factors based on their relative importance have offered a clear understanding of the most significant contributors to site suitability. The results emphasize the need for a holistic approach that considers environmental, infrastructural, and regulatory aspects to ensure sustainable and resilient housing developments in secondary cities like Musanze. It is evident from the study that the

GIS-based multicriteria analysis has provided a robust framework for identifying potential suitable sites for housing
development, offering urban planners and

V. ACKNOWLEDGMENT

The authors acknowledge the University of Lay Adventists of Kigali (UNILAK) for a conducive environment toward the completion of this research.

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