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GIS-based accessibility assessment of educational facilities in Nyamasheke district, Rwanda

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Abstract

Limited spatial assessment of educational accessibility remains a challenge in geographically complex regions such as Nyamasheke District, Rwanda, using Geographic Information Systems (GIS). Through network analysis, slope and elevation mapping, population density assessment and multi-criteria suitability evaluation, the research mapped existing schools, analysed travel distances and identified optimal sites for new facilities. Results showed that while educational facilities are generally well distributed, some sectors such as Ruharambuga, Bushekeri, Kanjongo and Kirimbi remain underserved due to rugged terrain and limited road infrastructure. Proposed new school sites were selected based on high population density, proximity to roads and favourable land characteristics to reduce walking distances and enhance equity. The findings highlight the usefulness of GIS-based spatial analysis for improving equitable educational planning in geographically constrained regions. The study recommends implementing the identified sites and improving road networks. This approach provides valuable insights for policymakers and can be replicated in other regions facing similar geographical challenges.

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INTRODUCTION

Education is universally recognized as a cornerstone of sustainable development and a fundamental human right (Kahn, 2008). Despite significant global advancements in educational infrastructure, disparities remain, particularly in rural and underprivileged regions. Geographic, socio-economic and infrastructural barriers often limit equitable access to education, undermining attendance rates and learning outcomes. These challenges are especially

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pronounced in rural areas, where accessibility is hindered by geographical isolation, inadequate transport and lack of infrastructure (Peer, 2024).

Geographical Information Systems (GIS) have emerged as a powerful tool to address these educational disparities by analyzing spatial data to optimize the location of educational facilities and resources. GIS enables policymakers to identify underserved areas, allocate resources effectively and assess the efficiency of existing infrastructure. For example, countries like India and Brazil have successfully used GIS to map educational facilities and identify regions with limited access to schools, leading to more targeted interventions (Aguilar et al., 2024).

In Africa, rural communities face acute educational challenges due to socio-economic inequalities, inadequate infrastructure and vast geographic distances (Zickafoose et al., 2024; Jere et al., 2025). GIS has proven transformative in countries like Nigeria and Kenya, where it has been used to map school catchment areas and identify regions that require urgent infrastructure investment (Kholoshyn et al., 2022; Murad et al., 2021).

Conceptual and Definitional Foundations:

Accessibility assessment is the systematic evaluation of the ease with which individuals can reach essential services and facilities, incorporating both spatial and non-spatial factors (G. Li et al., 2023). Within land surveying and GIS, it emphasizes measuring physical access through network analysis, proximity evaluation, and service area delineation while accounting for topographic and infrastructural constraints (Higgs et al., 2012; Franchi et al., 2024). Education facilities are physical spaces designed to provide learning opportunities, ranging from schools to specialized institutions. They form integral components of a community's educational infrastructure and are evaluated based on capacity, location, services, and accessibility to diverse populations (Barrett et al., 2019). Geographic Information System (GIS) is a framework for gathering, managing, and analyzing spatial data, enabling detailed maps and models for decision-making (Aschenbach, 1991). It integrates satellite imagery, census data, and field surveys to analyze patterns in the physical environment and supports strategic planning and policy development (Giaoutzi & Papadopoulou, 2021).

Theoretical Perspectives

Location theory, first developed by Johann Heinrich von Thünen and later expanded by Alfred Weber and Walter Christaller, remains a foundational framework for understanding the spatial arrangement of services (McPhearson et al., 2022). It explores how location influences accessibility, transportation costs, and spatial efficiency. Its principles of minimizing costs and maximizing accessibility provide a valuable basis for analyzing educational facility placement (Burgstahler & Cory, 2010). Strengths of location theory include its systematic spatial analysis and integration of quantitative data with GIS visualizations (Panagiotopoulou & Stratigea, 2017). However, it faces limitations such as reliance on simplified assumptions about homogeneous landscapes and underestimation of social and cultural factors. Despite these weaknesses, its structural approach supports strategic planning.

Network theory, originating from Euler and formalized through graph theory, conceptualizes systems as structures of nodes and links (Estrada, 2013). It is widely applied in geography and education accessibility studies (Vaz, 2024). Strengths include precise modeling, quantification of accessibility via network density, centrality, and shortest path measures, and integration with transportation modeling (Zou et al., 2024; Sarkar et al., 2021). Limitations stem from reliance on accurate spatial data and simplification of real-world complexities (Curtin, 2007). By applying network analysis through GIS, researchers can identify disparities, optimize placement, and enhance educational equity (Ball et al., 2017).

Empirical Evidence:

Empirical studies have consistently demonstrated the effectiveness of GIS in educational accessibility assessment. Through spatial data capture and visualization, GIS helps evaluate

school distribution and unequal access (Cobb, 2020). Murad et al. (2021) mapped schools in Jeddah to uncover disparities, while Sakti et al. (2021) integrated accessibility with environmental factors for balanced placement (Samani et al., 2024). Aguilar et al. (2024) explored web-based GIS for collaborative analysis (Li et al., 2020). Grieve and Olivier (2018) applied spatial coverage modeling in Rwanda's healthcare, offering transferable approaches for education (Huerta Munoz & Källestål, 2012). Kholoshyn et al. (2022) reviewed global GIS applications in schools, while Abulibdeh et al. (2024) revealed urban-rural disparities in Qatar (Chari, 2024). Beyond education, GIS has proven valuable in healthcare and public services (Wang, 2020), with applications in proximity analysis for dental institutions (Wu & Liu, 2022) and network analysis for transportation and emergency services (Albano et al., 2014; Cairney & Kippin, 2022).

Although GIS has been widely applied to assess educational facilities, a significant research gap remains in studies specifically addressing rural areas such as Nyamasheke District in Rwanda. Most existing studies focus on urban and peri-urban regions, leaving rural communities constrained by geographical barriers and limited infrastructure- largely underexplored. In Rwanda, GIS has been effectively utilized in healthcare and infrastructure (Niyonsenga et al., 2020), yet comprehensive applications to educational facilities remain limited. This study aims to fill this gap by applying GIS to evaluate educational facilities in Nyamasheke District, addressing the unique needs of rural populations and contributing to more equitable and evidence-based educational planning.

METHOD

Study Area

Nyamasheke District, located in the Western Province of Rwanda, lies along the eastern shores of Lake Kivu and covers an area of approximately 1,175 km². It is bordered by Karongi District to the north, Rusizi District to the south, Nyamagabe District to the east and Lake Kivu to the west. The district lies between latitudes 2°15'S to 2°40'S and longitudes 29°00'E to 29°30'E. Its topography is characterized by rugged hilly terrain with elevations ranging from 1,462 m to over 2,000 m above sea level (Figure 1).

This difficult terrain and scattered settlement patterns significantly influence land use, road networks and accessibility. The steep slopes and elevation variations directly affect travel time and connectivity to educational facilities, making accurate road network data essential for GIS-based accessibility analysis. Understanding the district's challenging landscape is therefore critical for assessing educational infrastructure gaps and optimizing school placement.

Data Collection

Data was collected through secondary sources, (Table 1):

Table 1. Data collection

Type of Data	Description	Source
Digital Elevation Model (DEM)	30m Resolution (STRM) 2022-10-06 day of data collection	USGS Earth Explorer
Population Data	2025-01-15, day of data collection	National Institute of Statistics of Rwanda (NISR)
Existing School Locations	Points location 2025-01-24, day of data collection	Nyamasheke District office
Road Networks	Vector Data (Shapefile) 2022-11-07, day of data collection	Rwanda Transport Development Agency (RTDA)
Land Use/Land Cover Data	Landsat 8- 30m resolution, 2024-01-05, day of data collection	Landsat Imagery from USGS
Administrative Boundaries	Vector data (Shapefile) 2022-12-20, day of data collection	NLA (Rwanda national land authority
Household Locations	The district has been well mapped on OpenStreetMap and data was extracted.	OpenStreetMap
Rivers Data	Vector data (Polyline) 2022-02-24, day of data collection	OpenStreetMap

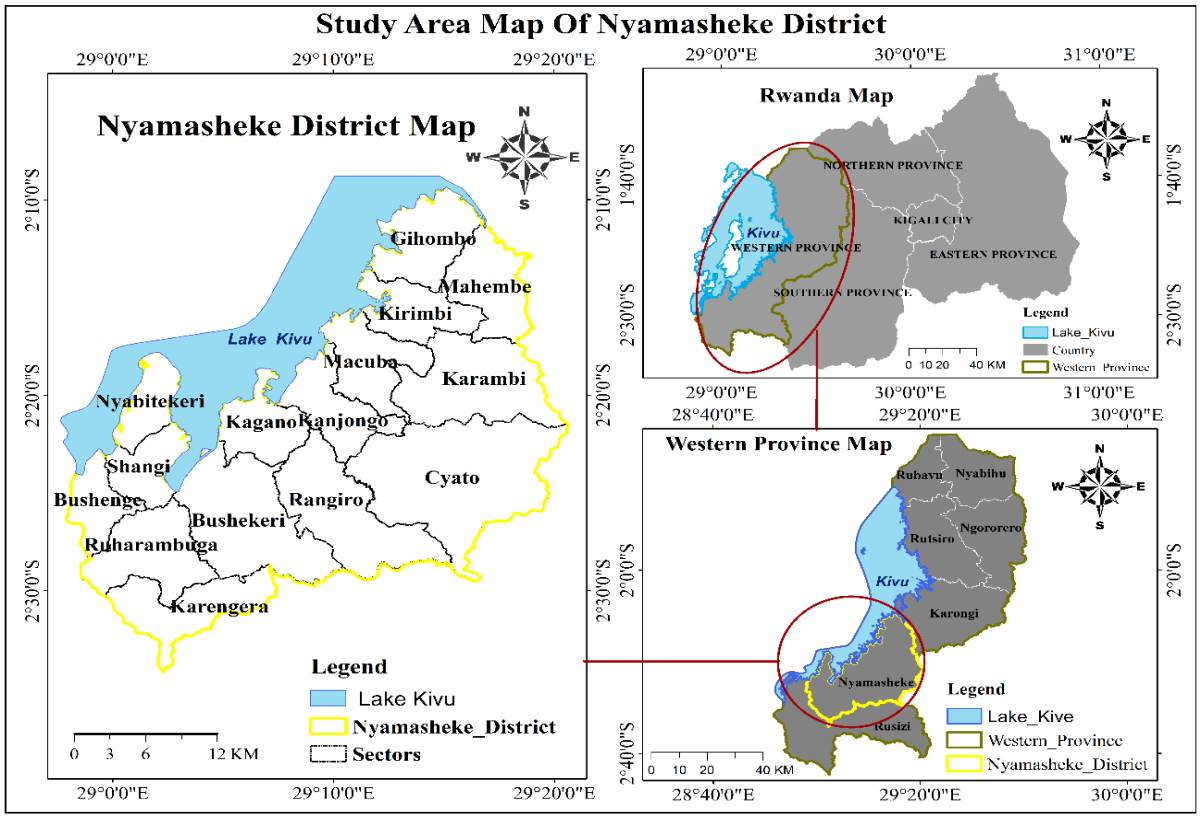


Figure 1. Study Area Map

The complete dataset of all 168 educational facilities in Nyamasheke District was obtained from the District Education Office. Table 2 in Appendix presents the full list of schools, including school name, sector, Point ID (POI ID), Government (Govt.) geographic coordinates (latitude and longitude), school status, and ownership type. Schools are categorized as Ecole Primaire (EP), Groupe Scolaire (GS), Ecole Secondaire (ES), Ecole Agri-Veterinary (EAV), Vocational Training Center (VTC), and Groupe Scolaire Frank Adamson (GSFA).

Data Processing

In the data processing phase, all collected datasets were systematically processed (Figure 3) using ArcGIS version 10.8. The study applied GIS-based techniques (Tables 3–6 and Equations 1–4), including slope and elevation analysis, population density mapping, and land use/land cover (LULC) evaluation. Settlement data were derived from residential building footprints extracted from OpenStreetMap, which were used as a proxy for settlement locations. These footprints do not represent individual households; instead, the centroid of each building footprint was used to represent settlement points for spatial analysis. Euclidean distance and network analysis were then performed based on these settlement centroids to assess accessibility to educational facilities in Nyamasheke District.

Digital Elevation Model (DEM) data were used to generate slope and elevation maps through the Spatial Analyst tools. These maps provided critical insights into terrain steepness and altitude, which significantly affect school accessibility and construction feasibility. Population density maps were created using spatial join and density analysis to identify areas with the highest demand for educational services. Existing schools, road networks, rivers and other physical features were digitized and georeferenced to establish a baseline for accessibility assessment.

All thematic layers were reclassified into suitability classes using the Reclassify tool for consistency. Multi-Criteria Decision Analysis (MCDA) was then applied through the Weighted Overlay tool (Table 3 – 6 & Equation 1 -4) to integrate the different factors and produce the final

suitability map for potential school locations. Finally, network analysis (Figure 2) was conducted using ArcGIS Network Analyst. Road networks were prepared with topological accuracy and assigned impedance attributes such as distance, slope and travel time. Service area analysis was performed to simulate real-world travel conditions from students' residences to schools, thereby identifying underserved sectors requiring improved educational access.

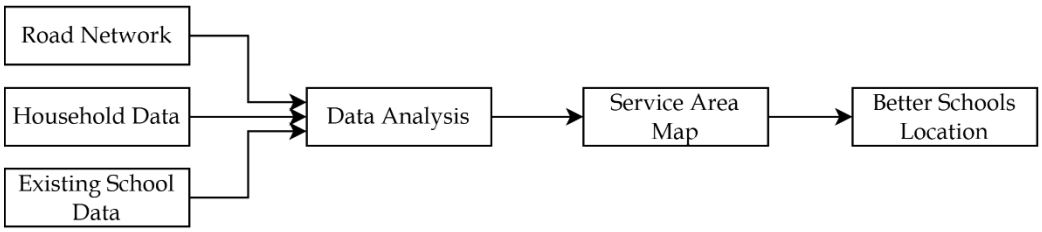


Figure 2. Network Analysis Diagram

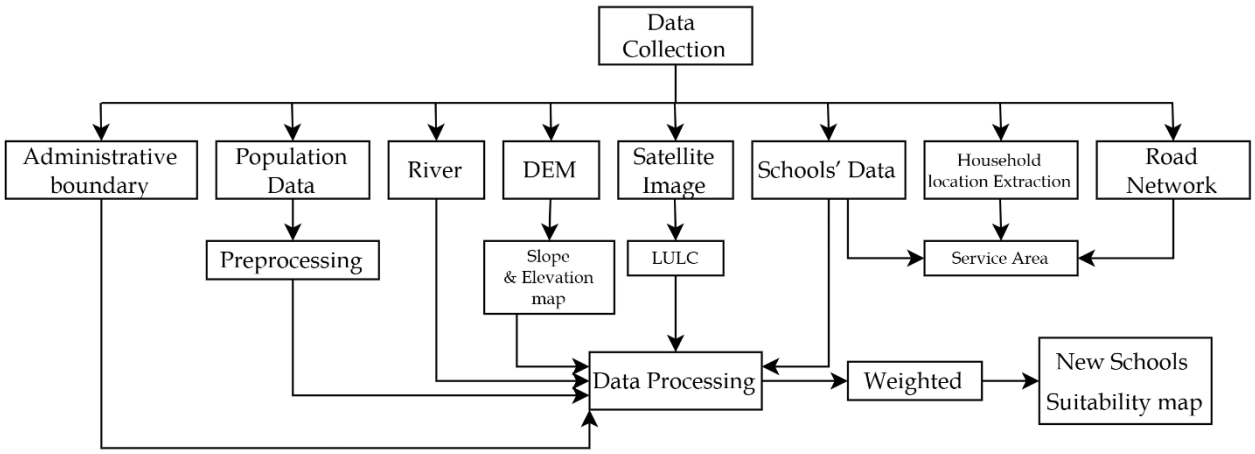


Figure 3. Methodology Flowchart

Suitability Analysis of New Schools

The suitability analysis for new school locations was conducted using multiple GIS techniques. Euclidean distance analysis was applied to measure straight-line distances from existing schools, roads, rivers and settlements. A Weighted Overlay Method (Table 3 -6, Equation 1-4) was then used to integrate key factors including slope, elevation, population density, distance to roads and land use/land cover to generate a comprehensive suitability map. This map identified the most suitable sites for establishing new educational facilities.

Service Area Analysis was performed using ArcGIS Network Analyst to evaluate real-world accessibility. The analysis assessed travel distances from student residences to schools based on MINEDUC recommended standards (2 km for primary schools and 3–5 km for secondary schools). By combining Euclidean distance, weighted overlay and service area results, the study successfully identified underserved areas with poor accessibility and highlighted optimal locations for new schools to improve educational equity in Nyamasheke District.

Table 3. Random Index Consistency

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

$$CR = \frac{\lambda_{max} - n}{n - 1} * \frac{1}{RI} = \frac{CI}{RI} \quad (1)$$

where: RI (Random Index) is a standard value based on the number of criteria, derived from randomly generated pairwise matrices.

Table 4. Pairwise Comparison Matrix

Criteria	Population Density	LULC	Slope	Elevation	Distance from Roads	Distance from settlements	Distance from rivers
Population density	1	2	3	4	5	6	7
LULC	0.5	1	2	3	4	5	6
Slope	0.33	0.5	1	2	3	4	5
Elevation	0.25	0.33	0.5	1	2	3	4
Distance from Roads	0.2	0.25	0.33	0.5	1	2	3
Distance from Settlements	0.17	0.2	0.25	0.33	0.5	1	2
Distance from Rivers	0.14	0.17	0.2	0.25	0.33	0.5	1
Sum	2.59	4.45	7.28	11.08	15.83	21.5	28

Table 5. Normalized Comparison Matrix

Criteria	Pop. Density	LULC	Slope	Ele-vation	Dist. from Roads	Dist. from Settle-ments	Dist. from Rivers	Weigh-ted Sum	Weight (w)	Weight (%)
Pop Density	0.386	0.449	0.412	0.361	0.316	0.279	0.25	2.453	0.351	35
LULC	0.193	0.225	0.275	0.271	0.253	0.233	0.214	1.664	0.237	23.8
Slope	0.127	0.112	0.137	0.181	0.189	0.186	0.179	1.111	0.158	15.9
Elevation	0.097	0.074	0.069	0.090	0.126	0.140	0.143	0.739	0.105	10.6
Distance from Roads	0.077	0.056	0.045	0.045	0.063	0.093	0.107	0.486	0.069	6.9
Distance from Settlements	0.066	0.045	0.034	0.030	0.032	0.047	0.071	0.324	0.046	4.6
Distance from Rivers	0.054	0.038	0.027	0.023	0.021	0.023	0.036	0.222	0.031	3.2
Sum	1	1	1	1	1	1	1	7	1	100

The acceptable threshold for the Consistency Ratio (CR) is ≤ 0.1 (or 10%). If CR > 0.1, the judgments are inconsistent and the decision-maker needs to refine the pairwise comparisons. If CR ≤ 0.1, the judgments are considered consistent and reliable.

$$\lambda_{max} = (0.386/1 * 0.351) + (0.225/1 * 0.237) + (0.137/1 * 0.158) + (0.090/1 * 0.105) + (0.063/1 * 0.069) + (0.047/1 * 0.046) + (0.036/1 * 0.031) = \mathbf{7.194} \quad (2)$$

$$CI = \frac{7.194 - 7}{7 - 1} = \mathbf{0.032} \quad (3)$$

$$CR = \frac{0.032}{1.32} = \mathbf{0.024} \quad (4)$$

Table 6. Ranked Criteria by Influence (High to Low):

Rank	Criteria	Weight	Weight (%)
1	Population Density	0.3518	35.2
2	Land Use Land Cover (LULC)	0.2377	23.8
3	Slope	0.1587	15.9
4	Elevation	0.1056	10.6
5	Distance from Roads	0.0694	6.9
6	Distance from Settlements	0.0463	4.6
7	Distance from Rivers	0.0318	3.2

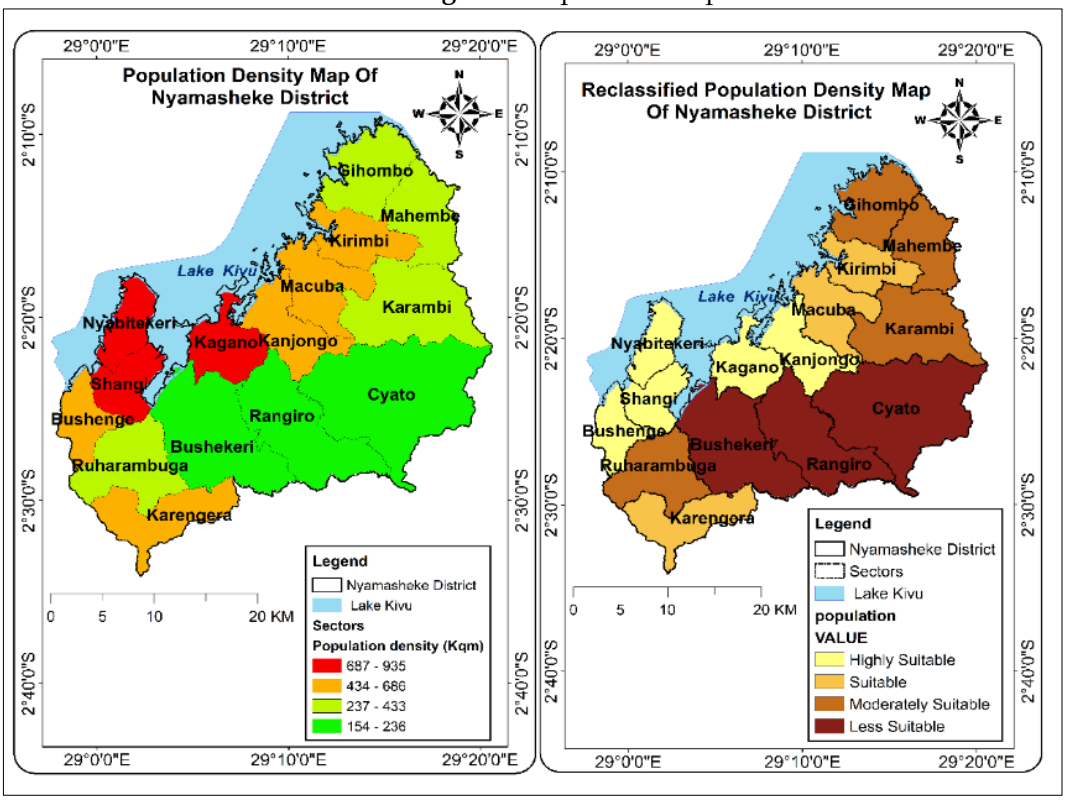
RESULTS AND DISCUSSIONS

Demographic Analysis

Population Distribution

The population density map (Figure 4) reveals considerable spatial variation across Nyamasheke District. High population concentrations are observed in central sectors such as Cyato, Bushenge, and parts of Karambi, while several remote and hilly sectors show relatively lower population density. The reclassified population density map further indicates that a significant proportion of the population resides in high-density zones. However, many of these high-density areas overlap with regions of poor accessibility. Notably, sectors such as Ruharambuga, Bushekeri, Kanjongo, and Kirimbi contain substantial populations located far from existing schools, highlighting critical gaps in educational access.

Figure 4. Population Map



The reclassified population map simplifies this complex demographic data into distinct categories, such as "highly suitable," suitable, "Moderate suitable" and "Less suitable" population density zones. This reclassification allows for a straightforward visual and analytical interpretation of areas with significant educational demand. GIS analysis can precisely identify communities that are geographically or functionally isolated from educational opportunities (Kerski *et al.*, 2013).

Area based on sectors of Nyamasheke District:

The pie chart showing population distribution by sector (Figure 5) highlights significant variation in population size across Nyamasheke District. Sectors such as Cyato (155,137 inhabitants) and Bushekeri (105,457 inhabitants) have the highest population concentrations, while several other sectors record comparatively lower populations. These high-population sectors represent areas with substantial demand for educational services. However, many of them overlap with zones of poor accessibility, meaning accessibility challenges affect a larger number of students. This spatial pattern underscores the need to prioritize school placement and infrastructure development in densely populated but underserved sectors to promote equitable access to education across the district.

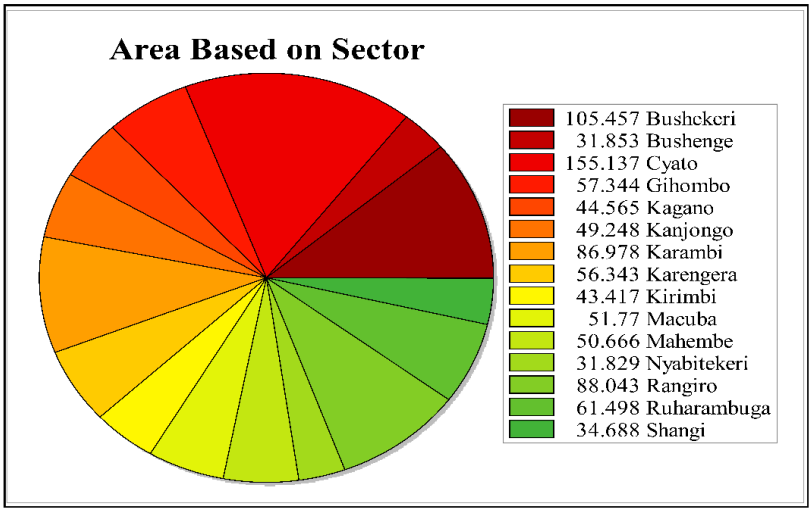


Figure 5. Area Based on Sectors Map

Existing Physical infrastructures of Nyamasheke District:

Nyamasheke District features key infrastructures (Figure 6), including road networks, rivers, vegetation, built-up areas, and existing schools. These elements significantly influence school accessibility and reveal gaps resulting from the district's rugged topography and scattered settlement patterns. The map developed in this study illustrates the spatial distribution of operational schools, highlighting clusters in more accessible central areas, isolated institutions in remote zones, and several underserved sectors with limited educational coverage. By combining this with demographic and road data, planners can identify well-connected zones and areas lacking facilities, supporting evidence-based planning for new schools in figure six. It is developed using GIS techniques that capture geographic coordinates and attribute data of each school site.

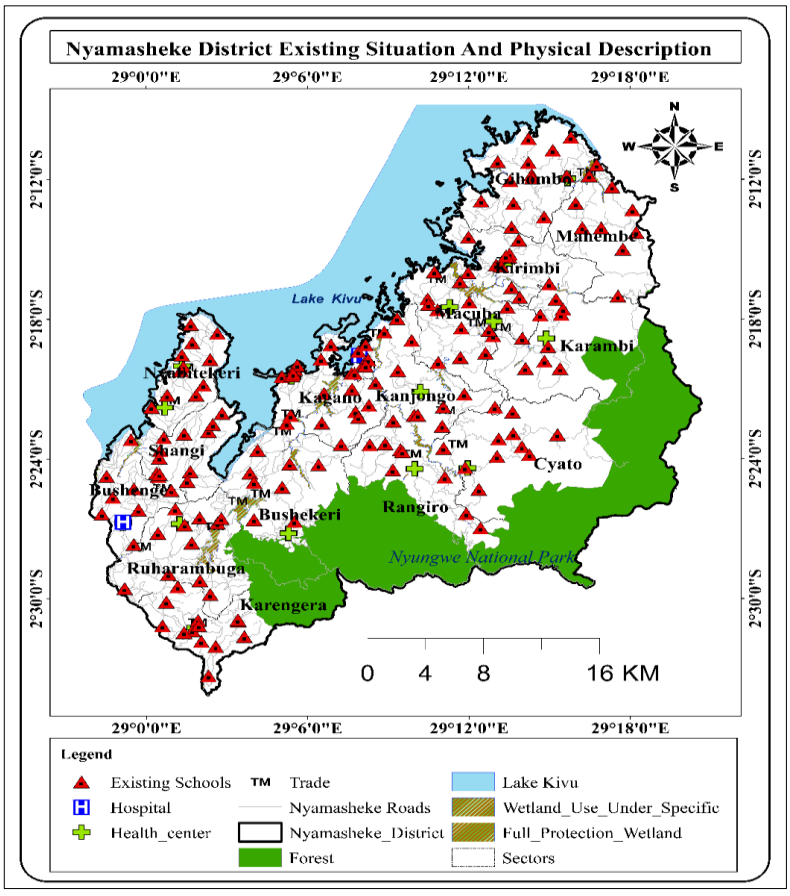


Figure 6. Existing and Physical Infrastructure Map

The map provides clear visual insights into the density, location and spread of primary and secondary schools throughout the district. From a spatial planning perspective, it helps identify clusters of schools, isolated institutions and areas that lack educational infrastructure. The map also supports accessibility analysis by allowing overlays with topographic, demographic and road network data to evaluate which schools are reachable and which are situated in challenging or underserved areas.

Slope Analysis

The Nyamasheke District Slope Map (Figure 7), showing various slope gradients (e.g., 0-10% to 40-80%), is critical as it highlights areas of varying steepness. Steep slopes significantly impede travel, increasing walking time and vehicle access difficult or impossible, thereby reducing effective accessibility to schools. The reclassified Slope Map simplifies this into a suitability index, typically ranging from "Highly Suitable, Suitable, moderate suitable and Low suitable" suitability for movement, by grouping similar slope ranges. This reclassification allows for a more direct interpretation of how terrain ruggedness affects accessibility. By integrating the locations of education facilities with these slope datasets in your GIS analysis, you can identify areas where students face significant topographic barriers to reaching schools, quantify the impact of terrain on travel impedance and pinpoint locations for potential infrastructure improvements or strategic school placement to enhance overall accessibility (Jiao & Feng, 2024).

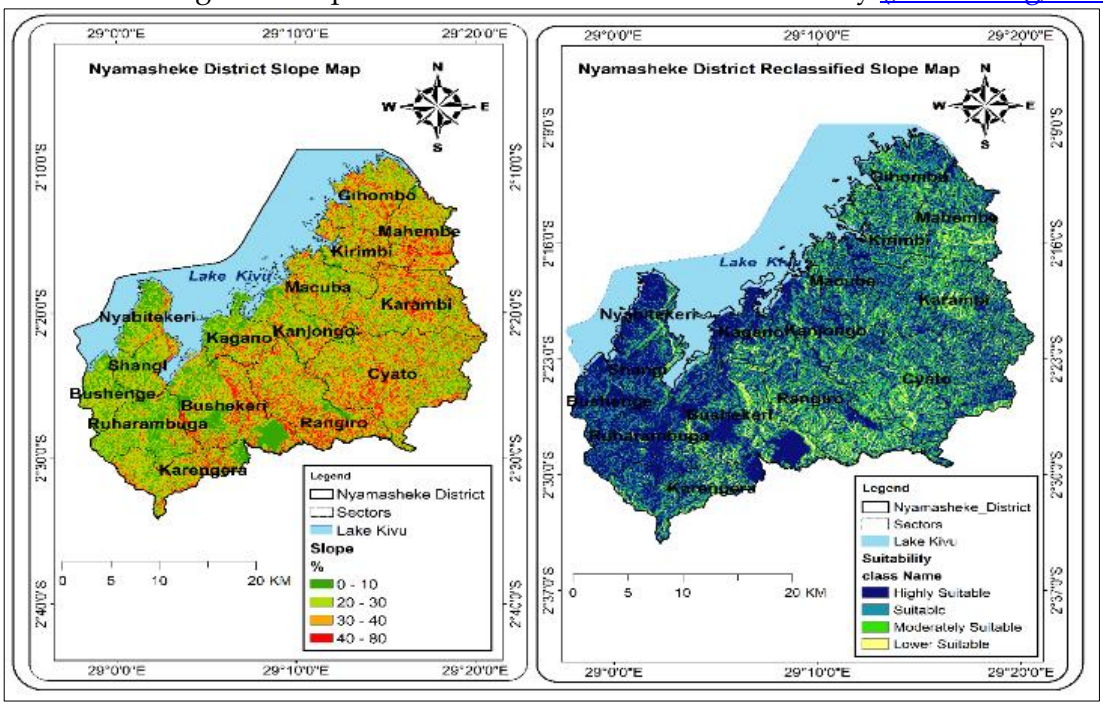


Figure 7. Slope Map

Elevation Analysis

An elevation map (Figure 8) and its classified version are critical in assessing education facility accessibility, particularly in land surveying because significant changes in elevation, like steep hills or valleys, directly impact how easily and quickly individuals can travel to education facilities (Marston, 2008). The raw elevation map provides precise topographical information, showing variations in height across the landscape. This is crucial because steep slopes or mountainous terrain significantly increase travel time and effort, acting a natural barrier to accessing schools. For instance, a school located across a deep valley might be geographically close but functionally distant due to elevation changes. The reclassified elevation map simplifies this complex data into suitability categories, making it easier to analyze areas that are more or less challenging to traverse. This reclassification helps in identifying zones where student commutes could be severely impacted by elevation, enabling a more accurate calculation of real-world travel costs. By integrating these elevation datasets with school location.

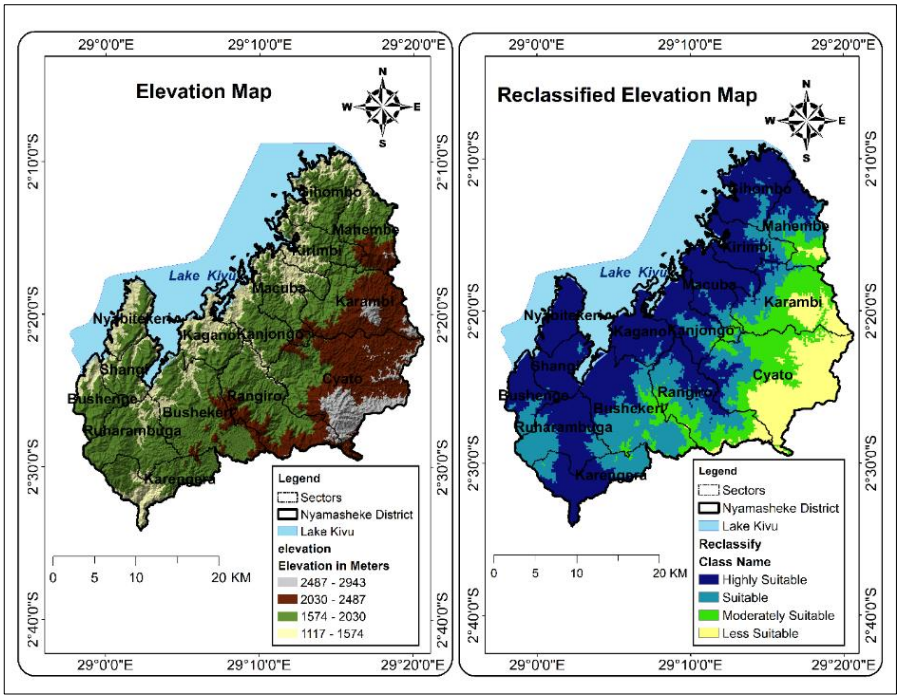


Figure 8. Elevation Map

Land Use Land Cover

The "Land Use/Land Cover Map" and "Land Use/Land Cover Reclassified Map" (Figure 9) are crucial for this study on the accessibility assessment of education facilities. The initial LULC map delineates various land categories such as Built Up, Water Bodies, Agriculture, Forestry and Crop Land (Regasa *et al.*, 2021). This is important for this study as it directly influences where educational facilities are located (e.g., built-up areas) and the types of land that might impede or facilitate access (e.g., dense forests or large agricultural areas could mean longer travel times or difficult terrain). The "Land Use/Land Cover Reclassified Map" further simplifies this by classifying the land into suitability levels, likely for development of access, ranging from four classes include "Highly suitable, suitable, moderate suitable, less suitable". This reclassification is invaluable for identifying areas that are more conducive to establishing or accessing educational facilities, helping to assess how current facilities are situated within these suitability zones and to pinpoint areas where accessibility might be inherently challenging due to less suitable land cover.

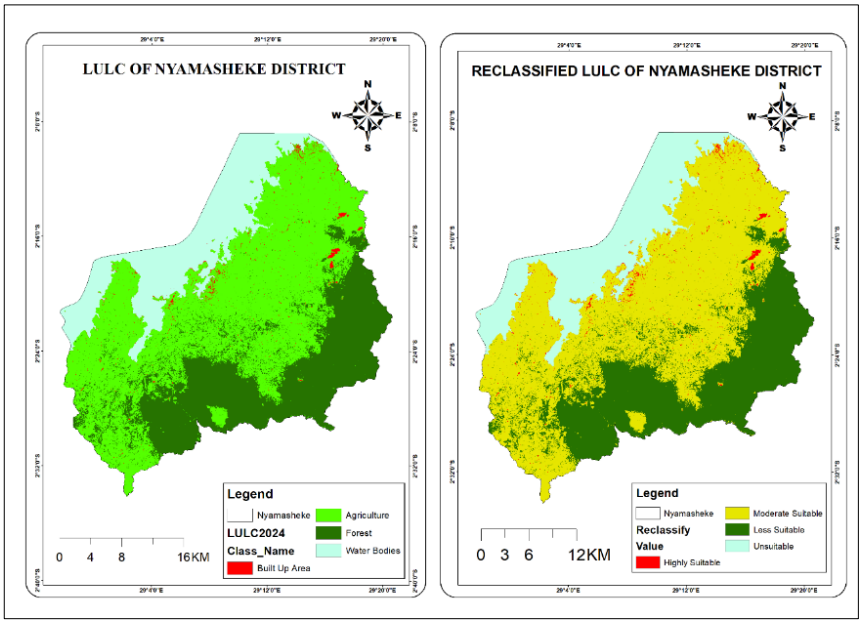


Figure 9. LULC Map

Service Area Map

The Service Area Map (Figure 10) is one of the key outputs used to assess spatial accessibility to educational facilities. The map delineates service-area polygons around schools and categorizes them into four accessibility classes: 2 km (High Accessibility Zone), 3 km (Accessible Zone), 4 km (Moderate Accessibility Zone), and 5 km (Low Accessibility Zone) (Hammad & Mohammed, 2023). Based on the planning principle that students should have reasonable walking access to educational facilities, the map enables both visual and quantitative assessment of school accessibility. Areas within the High Accessibility and Accessible Zones represent locations where students are likely to have adequate access to schools through the existing road network. In contrast, the Moderate Accessibility and Low Accessibility Zones indicate areas where students may experience greater travel distances and reduced access to educational services. By integrating existing schools, proposed schools, and the road network with the service-area polygons, the map provides a useful tool for identifying underserved communities and prioritizing locations for future school development and infrastructure improvement (Hammad & Mohammed, 2023).

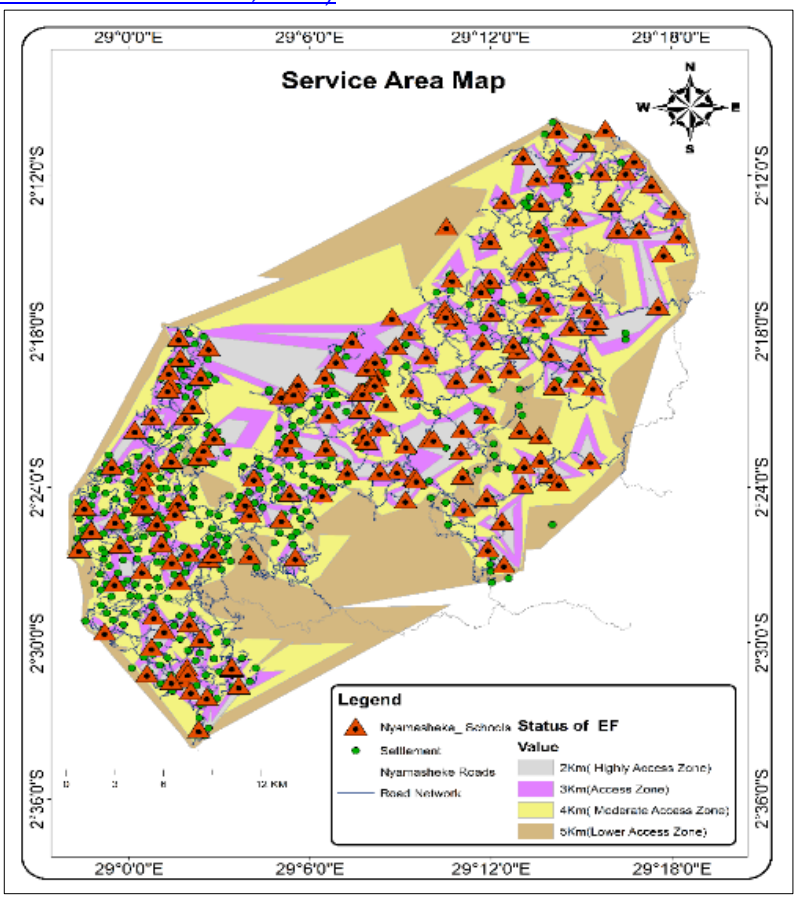


Figure 10. Service Area Map

Distance Analysis for accessibility

Distance from settlement:

The Euclidean distance (Figure 11) from settlement (or student homes) map shows the straight-line distance from each school to the nearest settlement or residential area. This helps determine how far students would need to travel to reach a school, assuming a direct path. The reclassified distance from settlement map takes this continuous distance data and organizes it into classified ranges (e.g.,0-3km, 4-5km, 5-6km), making it easier to analyze and interpret. Areas with shorter distances are considered to have better accessibility, while areas with longer distances highlight potential barriers to access. Reclassifying the distances helps planners identify which schools are conveniently located near communities and which may require additional

support like transportation services or the establishment of new schools to improve equitable accessibility.

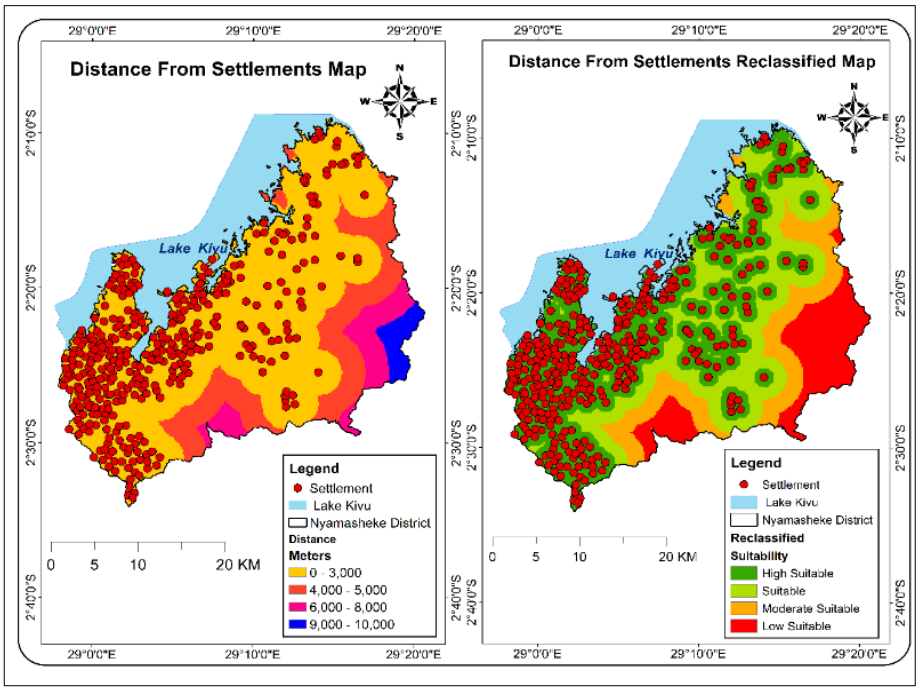


Figure 11. Distance from Settlements

Distance From Rivers:

The Euclidean distance (Figure 12) from rivers map shows the straight-line distance from each location to the nearest river. This is important because rivers can act as natural barriers that may limit or complicate access to schools, especially in areas without bridges or proper crossing infrastructure. The reclassified distance from rivers map takes the continuous distance values and groups them into classified ranges (0-500m, 600-1000m, etc.), making it easier to interpret how proximity to rivers might affect school accessibility. Areas very close to rivers may face challenges such as flood risk or lack of crossing points, while areas farther away may have fewer natural obstacles. This analysis helps planners identify high-risk zones or places where infrastructure improvements like bridges or alternative routes might be needed to improve access to education facilities (Canton, 2021).

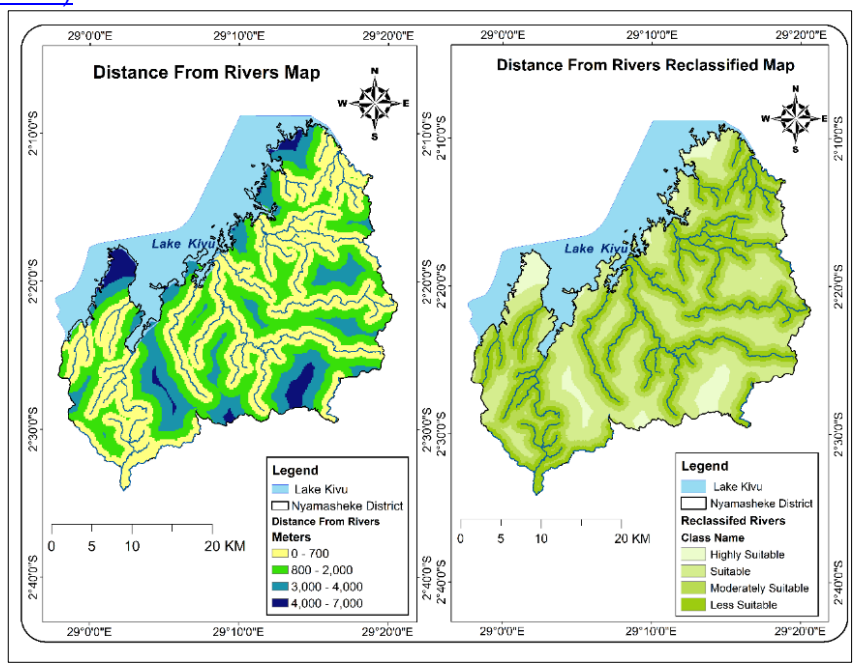


Figure 12. Distance from Rivers

The Euclidean distance from roads map (Figure 13) shows the straight-line distance from any location to the nearest road, which is crucial because roads are the primary means of accessing schools. Areas close to roads generally have better physical access to educational facilities, while areas farther away may face difficulties due to limited or no transport routes. The reclassified distance from roads map organizes this distance data into range categories (0-400m, 500-1000m, etc.) to clearly highlight zones with high, moderate, or low accessibility based on road proximity. This reclassification helps identify underserved communities that may need new roads, improved paths, or transport support to enhance access to schools. It also assists in planning where to prioritize infrastructure development to reduce educational access barriers caused by poor connectivity.

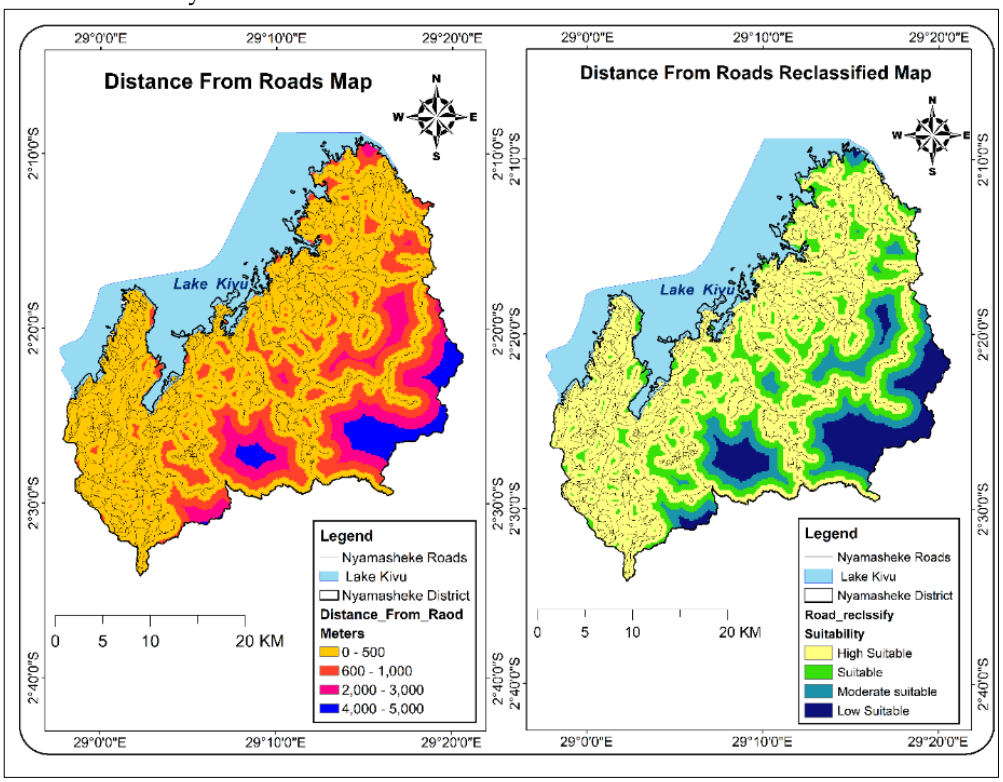


Figure 12. Distance from Roads

Suitability Analysis

Nyamasheke Site Suitability Analysis (Figure 14) for Education Facilities map presents a GIS- based evaluation of the most appropriate locations for establishing new schools within Nyamasheke District by combining key spatial factors influencing accessibility, such as proximity to settlements (student homes), roads, rivers and terrain. The map is classified into four suitability ranks: Highly Suitable (red), Suitable (yellow), Moderately Suitable (light green) and Low Suitable (blue) based on a Weighted overlay analysis using reclassification, Euclidean distances and other layers. The weighted overlay method is spatial analysis technique used in GIS to combine different types of data layers, such as slope, elevation, population density, land use and distance from roads, settlement, rivers, by measuring how suitable or not. The Weighted overlay method is useful because it integrates various factors that affect school accessibility in Nyamasheke District. Highly suitable areas are closest to settlements and roads and furthest from rivers or steep slopes, indicating the best accessibility for students and minimal construction barriers. Less suitable zones are more isolated, with poor road access or physical obstacles, making them less favorable for school development. This map supports the broader goal of accessibility assessment using GIS by identifying where students face the most difficulty reaching schools and guiding the placement of future educational infrastructure to promote equitable access across the district (Niyigaba, 2022).

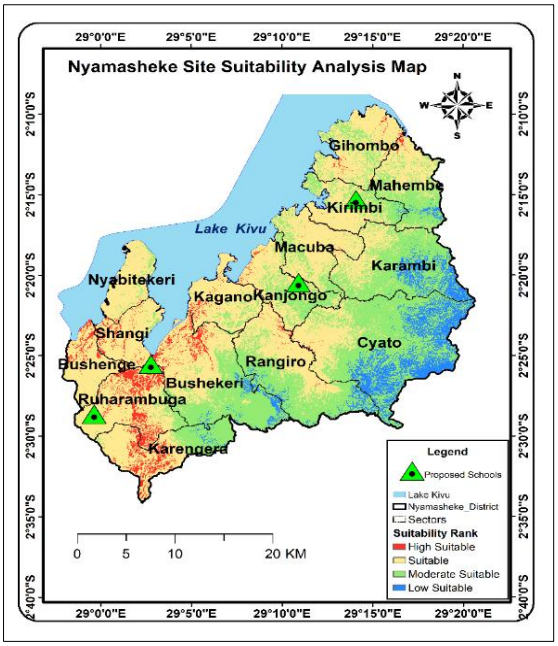


Figure 13. Suitability Analysis Map

The suitability map indicates that schools in Nyamasheke District are generally more accessible in areas located along major road corridors and trading centers, where terrain conditions are relatively gentle and transportation connectivity is better. In contrast, many rural and mountainous sectors are classified as low-suitability zones, suggesting that students may need to travel longer distances and face challenges associated with steep slopes and inadequate road infrastructure. These spatial disparities indicate unequal access to educational facilities, with well-connected areas being better served than remote communities. To improve educational equity, additional schools should be established in underserved sectors with relatively high population densities, while road infrastructure should be improved to enhance access to existing schools.

Existing and Proposed School of Nyamasheke District

Figure 15 presents the spatial distribution of existing schools alongside the proposed new school locations derived from the integrated GIS analysis. The map reveals distinct spatial patterns in educational accessibility across the district. Most existing schools are concentrated in central and relatively flat sectors such as Cyato, Bushenge, and parts of Karambi, where road networks are better developed and population density is relatively high. In contrast, several peripheral and hilly sectors, particularly Ruharambuga, Bushekeri, Kanjongo, and Kirimbi, show clear gaps in coverage.

The proposed new school sites were strategically identified by integrating multiple GIS layers including network service area analysis, population density, slope, elevation, distance to existing roads, and land use/land cover suitability. These locations were prioritized in high-density underserved areas that fall outside the recommended 2 km (primary) and 3–5 km (secondary) service zones, while maintaining favourable terrain and proximity to road networks. This multi-criteria approach ensures that new facilities will significantly reduce average walking distances for students in remote communities.

The findings align with previous studies in similar rugged terrains. For instance, Murad et al. (2021) and Abulibdeh et al. (2024) also found that uneven school distribution in areas with complex topography leads to significant accessibility inequities. By targeting these underserved sectors, the proposed locations address not only physical distance but also socio-economic disparities, supporting more equitable educational opportunities.

From a policy perspective, the results provide clear guidance for local authorities and the Ministry of Education. Implementing these proposed sites, coupled with targeted road

improvements in low-accessibility zones, would substantially enhance educational equity in Nyamasheke District.

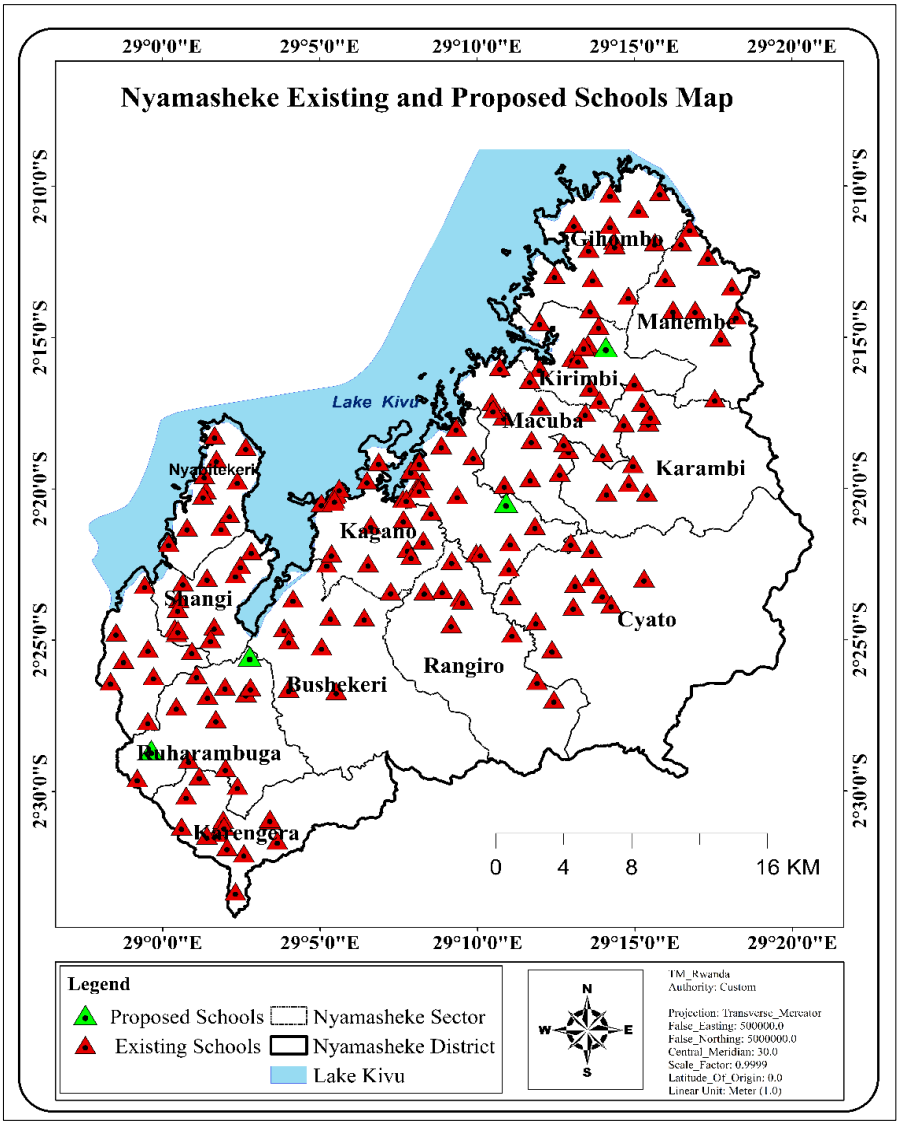


Figure 14. Existing and Proposed Schools Map

CONCLUSION

This study assessed the accessibility of educational facilities in Nyamasheke District using Geographic Information Systems (GIS), with a focus on network analysis, terrain evaluation and site suitability analysis. The integrated GIS approach successfully mapped existing schools, analysed travel distances and times and identified optimal locations for new educational facilities to enhance equitable access. Findings revealed that while educational facilities are generally well distributed across the district, rugged terrain, uneven school placement and limited road infrastructure continue to create accessibility challenges in several sectors. GIS analysis identified underserved areas, particularly in sectors with high population density and poor connectivity. Proposed new school sites, determined through weighted overlay and service area analysis, target these gaps to reduce walking distances and improve access for students.

Overall, the integration of GIS, network analysis, and suitability modelling proved effective for evaluating and addressing educational infrastructure challenges in Nyamasheke District. The methodology offers a replicable framework that can be adapted to other regions facing similar geographical and infrastructural constraints, thereby supporting more inclusive and evidence-based educational planning in Rwanda.

However, this study has several limitations. It relied primarily on secondary data, some of which may not fully reflect current ground conditions. The analysis is static and does not incorporate real-time population dynamics, seasonal road accessibility variations or the actual condition and capacity of existing school facilities. Furthermore, the study focused exclusively on physical accessibility and did not assess educational quality, enrolment pressures, or socio-cultural barriers to school attendance.

It is strongly recommended that local authorities and educational planners prioritize the implementation of the 4 new school sites identified through this GIS-based analysis to address existing accessibility gaps in Nyamasheke District and this should be replicated in other districts of Rwanda. For future research, scholars should build upon the current limitations by incorporating real-time population growth data, dynamic road conditions, and environmental factors. Also, studies could integrate qualitative approaches to assess school capacity, educational quality, and socio-cultural barriers. The development of interactive, web-based GIS platforms and the application of advanced techniques such as machine learning could further enhance the accuracy, timeliness, and usability of accessibility assessments in similar rural settings.

AUTHOR CONTRIBUTIONS

The authors made substantial and independent contributions to the conception and design of the study, data acquisition, analysis and interpretation of data, as well as drafting and revising the manuscript.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest regarding the publication of this manuscript.

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APPENDIX

Table 2. Complete List of Educational Facilities in Nyamasheke District (2025)

Schools Name	Sector	POI ID	Latitude	Longitude	Schools Status	Ownership
EP Bwanama	Cyato	166	-2.42181	29.20614	Govt. Aided	Catholic
GS Yove	Cyato	165	-2.40628	29.19761	Govt. Aided	Catholic
GS Kanjongo	Cyato	168	-2.39244	29.18428	Govt. Aided	Catholic
EP Cyato	Cyato	164	-2.38572	29.21842	Govt. Aided	Catholic
GS Mutuntu	Cyato	162	-2.39142	29.23283	Govt. Aided	Protestant
EP Rwaramba	Cyato	1266	-2.382103	29.227421	Govt. Aided	Protestant
EP Ruhengeri	Cyato	160	-2.36653	29.22711	Govt. Aided	Catholic
EP Hangari	Cyato	2	-2.382709	29.254924	Public	Govt.
EP Rwumba	Cyato	167	-2.39825	29.21744	Govt. Aided	Catholic
EP Ntsinduka	Cyato	163	-2.397	29.23747	Govt. Aided	Protestant
G.S St Kizito Fumba	Mahembe	80	-2.22197	29.30147	Govt. Aided	Catholic
E.P Gabiro	Mahembe	78	-2.19756	29.27461	Govt. Aided	Catholic
E.P Mahembe	Mahembe	94	-2.21717	29.26622	Govt. Aided	Catholic
G.S Mugonero	Mahembe	85	-2.18975	29.27925	Govt. Aided	ADEPR
E.P Binogo	Mahembe	90	-2.23467	29.27031	Govt. Aided	EMLR
G.S Nyagatare	Mahembe	83	-2.23483	29.28206	Govt. Aided	Catholic
E.P Bigali	Mahembe	88	-2.24997	29.2955	Govt. Aided	EMLR
GS Giko	Mahembe	81	-2.23794	29.30372	Govt. Aided	Catholic
E.P Nyarusiza	Mahembe	84	-2.28358	29.29244	Govt. Aided	ADEPR
EP Giti	Mahembe	4	-2.205475	29.28881	Public	
EP Bumazi	Ruharambuga	38	-2.45317	29.00725	Govt. Aided	Catholic
EP Rusambu	Ruharambuga	28	-2.43583	29.01797	Public	Govt.
EAV Ntentezi	Ruharambuga	42	-2.44586	29.04411	Public	Govt.
EP Ntendezi	Ruharambuga	41	-2.44256	29.0465	Govt. Aided	Catholic
EP Ruharambuga	Ruharambuga	40	-2.46014	29.02817	Govt. Aided	Catholic
GS Kamonyi	Ruharambuga	24	-2.44714	29.02375	Govt. Aided	Protestant
VTC Ntendezi	Ruharambuga	43	-2.44211	29.03306	Private	Protestant
GS Gihinga	Ruharambuga	34	-2.48247	29.01372	Govt. Aided	Protestant
GS Bigutu	Ruharambuga	35	-2.49261	28.98656	Govt. Aided	Protestant
GS Rwabidege	Ruharambuga	44	-2.487	29.03328	Govt. Aided	Catholic
EP Gatanga	Ruharambuga	45	-2.49693	29.03961	Public	Govt.
GS Gahisi	Rangiro	131	-2.41314	29.18503	Govt. Aided	Protestant
GS Banda	Rangiro	150	-2.43914	29.19831	Govt. Aided	Protestant
ES Rangiro	Rangiro	149	-2.39342	29.15758	Govt. Aided	Protestant
EP Bigeyo	Rangiro	146	-2.40789	29.15286	Govt. Aided	Protestant
E.P Kaneke	Rangiro	5	-2.38912	29.14813	Public	Govt.
E.P Rangiro	Rangiro	1452	-2.39486	29.15886	Govt. Aided	Protestant
E.P Kamatsira	Rangiro	482	-2.37292	29.15308	Govt. Aided	Protestant
E.P Gasebeya	Rangiro	453	-2.4045	29.1606	Govt. Aided	Protestant
E.P Murambi	Rangiro	342	-2.3898	29.1636	Govt. Aided	Protestant
G.S.Mpabe	Rangiro	153	-2.38989	29.13856	Govt. Aided	Protestant
E.P Gasanane	Rangiro	151	-2.44944	29.20717	Govt. Aided	Protestant
EP Korwe	Kanjongo	204	-2.36278	29.18414	Govt. Aided	Protestant
EP Kivoga	Kanjongo	203	-2.37661	29.18344	Govt. Aided	Protestant
EP Gatebe	Kanjongo	202	-2.35372	29.19717	Govt. Aided	Protestant
EP Kamabuye	Kanjongo	152	-2.36875	29.16606	Govt. Aided	Protestant
EP Nyarubura	Kanjongo	201	-2.36297	29.21614	Govt. Aided	Protestant
GS St Paul Tyazo	Kanjongo	213	-2.332	29.13494	Govt. Aided	Catholic
EP Ruheru B	Kanjongo	46	-2.33678	29.15606	Govt. Aided	Catholic
EP Gitongo	Kanjongo	208	-2.30925	29.14764	Govt. Aided	Catholic
EP Gitambi	Kanjongo	210	-2.29956	29.15553	Govt. Aided	Protestant
GS Muraza	Kanjongo	209	-2.31528	29.16456	Govt. Aided	Protestant
EP Kibogora	Kanjongo	215	-2.32914	29.13756	Govt. Aided	Adventist
EP Nyagisasa	Kanjongo	211	-2.34575	29.14214	Govt. Aided	Adventist
GS Ruheru A	Kanjongo	44	-2.36875	29.16833	Govt. Aided	Adventist
St Mathews School	Kanjongo	6	-2.33886	29.127273	Private	Adventist
GSFA Kibogora	Kanjongo	219	-2.32317	29.1315	Govt. Aided	Adventist
E.S. Tyazo	Kanjongo	212	-2.33883	29.12908	Govt. Aided	Adventist
TVET Tyazo	Kanjongo	214	-2.33344	29.13597	Govt. Aided	Adventist
GS Maseka	Kanjongo	7	-2.318517	29.136037	Public	Adventist
E.P Nyakibingo	Shangi	66	-2.38033	29.03867	Govt. Aided	Adventist
GS Ngoboka	Shangi	8	-2.39396	29.00858	Public	Adventist
GS St Michel Mpishyi	Shangi	67	-2.40911	29.02731	Govt. Aided	Adventist
GS Bikunda	Shangi	64	-2.37531	29.04125	Govt. Aided	Adventist
E.P Mugera	Shangi	62	-2.36742	29.04703	Govt. Aided	Adventist

Schools Name	Sector	POI ID	Latitude	Longitude	Schools Status	Ownership
G.S St Dominic Savion Nyamugari	Shangi	61	-2.38214	29.02356	Govt. Aided	Adventist
E.S Gafunzo	Shangi	58	-2.39925	29.00806	Public	Adventist
E.S St Francois	Shangi	60	-2.41261	29.00739	Govt. Aided	Adventist
G.S St Jean Bosco	Shangi	59	-2.41011	29.00644	Govt. Aided	Adventist
EP Ngoboka Adepr	Shangi	56	-2.38475	29.01086	Govt. Aided	Adventist
VTC Shangi	Shangi	153	-2.41097	29.00814	Govt. Aided	Adventist
EP Mataba	Shangi	9	-2.415987	29.02543	Public	Adventist
E.P Kanyinya	Karengera	54	-2.51589	29.05694	Govt. Aided	Adventist
E.P Rubona	Karengera	52	-2.52711	29.06069	Public	Adventist
GS Gashashi	Karengera	48	-2.50232	29.01242	Govt. Aided	Adventist
E.P Rwintare	Karengera	47	-2.49147	29.01944	Govt. Aided	Adventist
E.P Mpinga	Karengera	55	-2.55514	29.0385	Govt. Aided	Adventist
G.S St Paul Karengera	Karengera	53	-2.53414	29.04294	Govt. Aided	Adventist
E.P Rurama	Karengera	56	-2.51933	29.00997	Public	Adventist
E.P Mwezi	Karengera	50	-2.52281	29.02856	Govt. Aided	Adventist
E.P Nyanunda	Karengera	51	-2.53058	29.03408	Govt. Aided	Adventist
GS Nyarusange	Karengera	58	-2.51553	29.03203	Govt. Aided	Adventist
VTC Mwezi	Karengera	155	-2.52417	29.02339	Govt. Aided	Adventist
TTC Mwezi	Karengera	10	-2.519181	29.032448	Public	Adventist
GS Gasayo	Karengera	11	-2.515075	29.056742	Public	Adventist
GS. Cyimpindu	Kirimbi	67	-2.27747	29.22642	Govt. Aided	Adventist
E.P Kagunga	Kirimbi	68	-2.28442	29.23147	Govt. Aided	Adventist
E.P Cyangabo	Kirimbi	61	-2.2555	29.22481	Govt. Aided	Adventist
G.S Karengera	Kirimbi	62	-2.25353	29.22525	Govt. Aided	Adventist
E.P Nduba	Kirimbi	3	-2.24342	29.23097	Govt. Aided	Adventist
G.S Kaburiro	Kirimbi	70	-2.27481	29.24981	Govt. Aided	Adventist
E.P Gacumbi	Kirimbi	57	-2.26683	29.19964	Govt. Aided	Adventist
G.S Karengera Gitwa	Kirimbi	58	-2.26131	29.21694	Govt. Aided	Adventist
G.S Kirimbi	Kirimbi	55	-2.27331	29.19456	Govt. Aided	Adventist
VTC Karengera	Kirimbi	59	-2.26214	29.22	Govt. Aided	Adventist
GS Mushungo	Kirimbi	64	-2.23247	29.17556	Govt. Aided	Adventist
E.P Nyabinaga	Kirimbi	60	-2.25489	29.22303	Govt. Aided	Adventist
GS Nyamure	Kirimbi	65	-2.24133	29.19975	Govt. Aided	Adventist
GS Remera A	Bushenge	74	-2.42131	28.99233	Govt. Aided	Adventist
GS Bushenge	Bushenge	70	-2.43647	28.99517	Govt. Aided	Adventist
GS Kiziba	Bushenge	75	-2.42744	28.97933	Govt. Aided	Adventist
EP Gitwa A	Bushenge	71	-2.41236	28.97542	Govt. Aided	Adventist
E.P Gashirabwoba	Bushenge	78	-2.46117	28.99217	Govt. Aided	Adventist
E.P Mwito	Bushenge	61	-2.38617	28.99056	Govt. Aided	Adventist
EP Nyarutovu	Bushenge	72	-2.42256	29.0155	Govt. Aided	Adventist
EP Rwashyamba	Bushenge	12	-2.43933	28.97243	Govt. Aided	Adventist
E.P Ruhamagariro	Nyabitekeri	47	-2.31006	29.04417	Govt. Aided	Adventist
GS St Vincent De Paul Bunyenga	Nyabitekeri	46	-2.32878	29.03969	Govt. Aided	Adventist
GS Adventist Nyamirundi	Nyabitekeri	154	-2.31689	29.02858	Govt. Aided	Adventist
EP Bucumba	Nyabitekeri	48	-2.30383	29.02764	Govt. Aided	Adventist
GS Ste Marie Merci Muyange	Nyabitekeri	51	-2.33408	29.02303	Govt. Aided	Adventist
G.S. Buhokoro	Nyabitekeri		-2.336837	29.021526	Govt. Aided	Adventist
EP Cyamuti	Nyabitekeri	49	-2.32569	29.02217	Govt. Aided	Adventist
GS St Maximilien Kolbe Mukoma	Nyabitekeri	44	-2.35442	29.01303	Govt. Aided	Adventist
E.P. Gafuba	Nyabitekeri	54	-2.36306	29.00331	Govt. Aided	Adventist
Ep Bunyangurube	Nyabigdkeri	43	-2.35436	29.03103	Govt. Aided	Adventist
E.P Nyabitekeri	Nyabitekeri	14	-2.3471	29.03548	Public	Adventist
EP Mweya	Karambi	50	-2.29714	29.24422	Govt. Aided	Adventist
E.P Ngange	Karambi	47	-2.29672	29.25728	Govt. Aided	Adventist
GS Rurembo	Karambi	15	-2.33018	29.246849	Public	Adventist
GS Rugano	Karambi	42	-2.312	29.215	Govt. Aided	Adventist
GS Kabuga	Karambi	30	-2.308156	29.212501	Public	Adventist
GS Karambi	Karambi	38	-2.31972	29.24906	Govt. Aided	Adventist
GS Rugabe	Karambi	43	-228636	29.28664	Govt. Aided	Adventist
GS Cyiya	Karambi	45	-2.28581	29.25403	Govt. Aided	Adventist
EP Rudaga	Karambi	41	-2.3353	29.23511	Govt. Aided	Adventist
EP Kageyo	Karambi	40	-2.33544	29.2565	Govt. Aided	Adventist
C O Mburabuturo	Karambi	46	-2.2929444	29.2583611	Public	Adventist
EP Ntumba	Kagano	28	-2.30547	29.12333	Govt. Aided	Adventist

Schools Name	Sector	POI ID	Latitude	Longitude	Schools Status	Ownership
GS Shara	Kagano	29	-2.31842	29.1145	Govt. Aided	Adventist
Shara Foundation	Kagano	31	-2.32866	29.10827	Govt. Aided	Adventist
EP Nyakabingo	Kagano	23	-2.35011	29.12756	Govt. Aided	Adventist
GS Gitwa	Kagano	33	-2.36633	29.12973	Public	Adventist
G S Gitwa B	Kagano	22	-2.37022	29.13161	Govt. Aided	Adventist
EP Remera B	Kagano	20	-2.36164	29.13803	Govt. Aided	Adventist
EP Rwangoma	Kagano	21	-2.38972	29.12078	Govt. Aided	Adventist
EP Gitaba	Kagano	26	-2.37444	29.10886	Govt. Aided	Adventist
GS Kinini	Kagano	36	-2.37451	29.087	Public	Adventist
EP Mutusa	Kagano	25	-2.36894	29.08947	Govt. Aided	Adventist
Joyful	Kagano	37	-2.34108	29.08415	Private	Adventist
GS ST Nicolas Nyamashske A	Kagano	19	-2.3405	29.09036	Govt. Aided	Adventist
EP St Catherine Nyamasheke B	Kagano	18	-2.33675	29.09131	Govt. Aided	Adventist
GS St Joseph	Kagano	17	-2.33586	29.09208	Govt. Aided	Adventist
ISF Nyamasheke	Kagano	16	-2.33294	29.09356	Govt. Aided	Adventist
TVET St Augustin Nyamasheke	Kagano	38	-2.33922	29.09108	Private	Adventist
GS Makoko	Kagano	27	-2.35317	29.11025	Govt. Aided	Adventist
EP Buhinga	Bushekeri	39	-2.4202	29.08421	Public	Adventist
EP Bitare	Bushekeri	63	-2.41003	29.06427	Public	Adventist
EP Mpumbu	Bushekeri	88	-2.40417	29.10678	Govt. Aided	Adventist
G.S. Nyanza	Bushekeri	86	-2.41675	29.06681	Govt. Aided	Adventist
GS Bushekeri	Bushekeri	90	-2.40358	29.08889	Govt. Aided	Adventist
Yove Primary School	Bushekeri	1	-2.44342	29.06672	Govt. Aided	Adventist
EP Ngoma	Bushekeri	85	-2.39378	29.06906	Govt. Aided	Adventist
GS Gisakura	Bushekeri	87	-2.44469	29.09192	Public	Adventist
E.P Mbogo	Gihombo	156	-2.21736	29.22775	Govt. Aided	Adventist
E.P Rwamatamu	Gihombo	149	-2.20108	29.22567	Govt. Aided	Adventist
G.S Nyakanyinya	Gihombo	119	-2.19683	29.23906	Govt. Aided	Adventist
E.P Bwerankori	Gihombo	126	-2.17083	29.23706	Govt. Aided	Adventist
E.P Musengesi	Gihombo	128	-2.18803	29.237	Govt. Aided	Adventist
GS Viro	Gihombo	141	-2.17928	29.25208	Govt. Aided	Adventist
E.P Birehe	Gihombo	155	-2.18742	29.21794	Govt. Aided	Adventist
E.P Gihombo	Gihombo	157	-2.22703	29.24672	Govt. Aided	Adventist
GS Jarama	Gihombo	154	-2.23431	29.22647	Govt. Aided	Adventist
E.P Rusuzumiro	Gihombo	143	-2.16994	29.26333	Govt. Aided	Adventist
G.S Kibingo	Gihombo	146	-2.19753	29.26072	Govt. Aided	Adventist
G.S Gitsimbwe	Gihombo	152	-2.21553	29.20764	Govt. Aided	Adventist
Gihombo Tvet School	Gihombo	69	-2.199031	29.239445	Public	Adventist
EP Buhoro Adv	Macuba	192	-2.2915	29.22386	Govt. Aided	Adventist