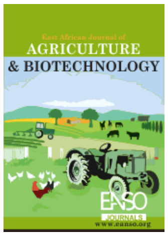

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Original Article

Assessing the Potential of Rooftop and Wall-Based Urban Agriculture for Food Security Enhancement in Gasabo District, City of Kigali, Rwanda

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Food Security, GIS, Household Survey, Rwanda, Spatial Analysis, Urban Agriculture.

ABSTRACT

This study evaluates the potential of rooftop and wall-based urban agriculture to enhance food security in the Gasabo District of Kigali, Rwanda. It combines GIS and remote sensing techniques to map suitable urban farming spaces and uses a stratified sampling technique to select 400 household heads for assessment using the Household Food Insecurity Access Scale (HFIAS). The findings show that 41.5% of the households experience moderate to severe food insecurity, and approximately 32% of rooftops and walls are structurally appropriate for urban agriculture. While 57.8% of households express willingness to adopt rooftop or wall gardening, 67.4% cite structural and financial constraints. A strong positive correlation ($r = 0.68$, $p < 0.01$) was observed between urban agriculture adoption and improved food security. The study recommends prioritising high-suitability sectors such as Kinyinya and Ndera for pilot projects and promoting lightweight hydroponic and vertical farming systems tailored to urban structures. These findings support the integration of urban agriculture into Kigali's urban planning to enhance food resilience and sustainability.

APA CITATION

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INTRODUCTION

Food insecurity is a growing global issue, especially in urban areas where food availability and access are greatly impacted by climate change, rapid urbanisation, and limited agricultural space (Palanisamy & Parthasarathy, 2016). Prior studies evaluating the potential of rooftop and wall-based urban agriculture for enhancing food security have demonstrated that urban agriculture can be a practical way to increase food security by using underutilised urban spaces for food production.

For example, studies conducted in places like New York and Nairobi have shown how rooftop and wall gardening may improve local food access and lessen reliance on the outside food supply chain (Khan et al., 2020). In addition to promoting food security, these urban agricultural projects also improve environmental sustainability, encourage community involvement, and create job possibilities (Lin et al., 2017). Cities may use their existing infrastructure to alleviate food shortages by turning walls and rooftops into productive agricultural zones (De Zeeuw et al., 2017). This is especially useful in highly populated places where traditional farming is unfeasible. By encouraging communal gardening, this strategy not only boosts food production but also reduces the urban heat island effect, enhances air quality, and fortifies community bonds (Oikonomaki et al., 2024).

Despite these encouraging results, Rwanda has not received much attention in the literature yet, despite the country's fast urbanisation and population increase, making food security a critical concern. Given Rwanda's distinct socioeconomic environment, which is marked by rapid urbanisation and a scarcity of arable land, local studies are required to determine if urban agriculture is a viable approach to improving food security (Nzeyimana, 2021).

Specifically, the geographical potential for rooftop and wall-based farming in Kigali, particularly in the Gasabo District, is not well supported by empirical data. Although global research emphasises the advantages of urban agriculture, local studies have not sufficiently examined the socioeconomic hurdles that prevent its household adoption or whether rooftops and wall surfaces are physically appropriate for farming (Nagle et al., 2016).

By examining the potential of wall-based and rooftop urban agriculture to enhance food security in Kigali, Rwanda's Gasabo District, this study aims to bridge this gap. The main aim of this study is to assess the potential of urban agriculture on rooftops and walls to improve food safety in the Gasabo district of Kigali City, Rwanda. Specifically, this study intended to: (1) assess the availability of roof and wall spaces suitable for urban agriculture in Gasabo district, (2) evaluate the current state of food security among households in the Gasabo district, and (3) analyze the relationship between the rooftops and walls' urban agriculture practices and food security enhancement in the Gasabo district.

MATERIALS AND METHODS

Study Area Description

The study was conducted in the Gasabo district, located in Kigali, Rwanda, which has a population of 879,505 with a density of 2,056/km2, with a growth rate of 5.2% (District Administrative Map, 2023). Gasabo district is divided into 15 sectors,

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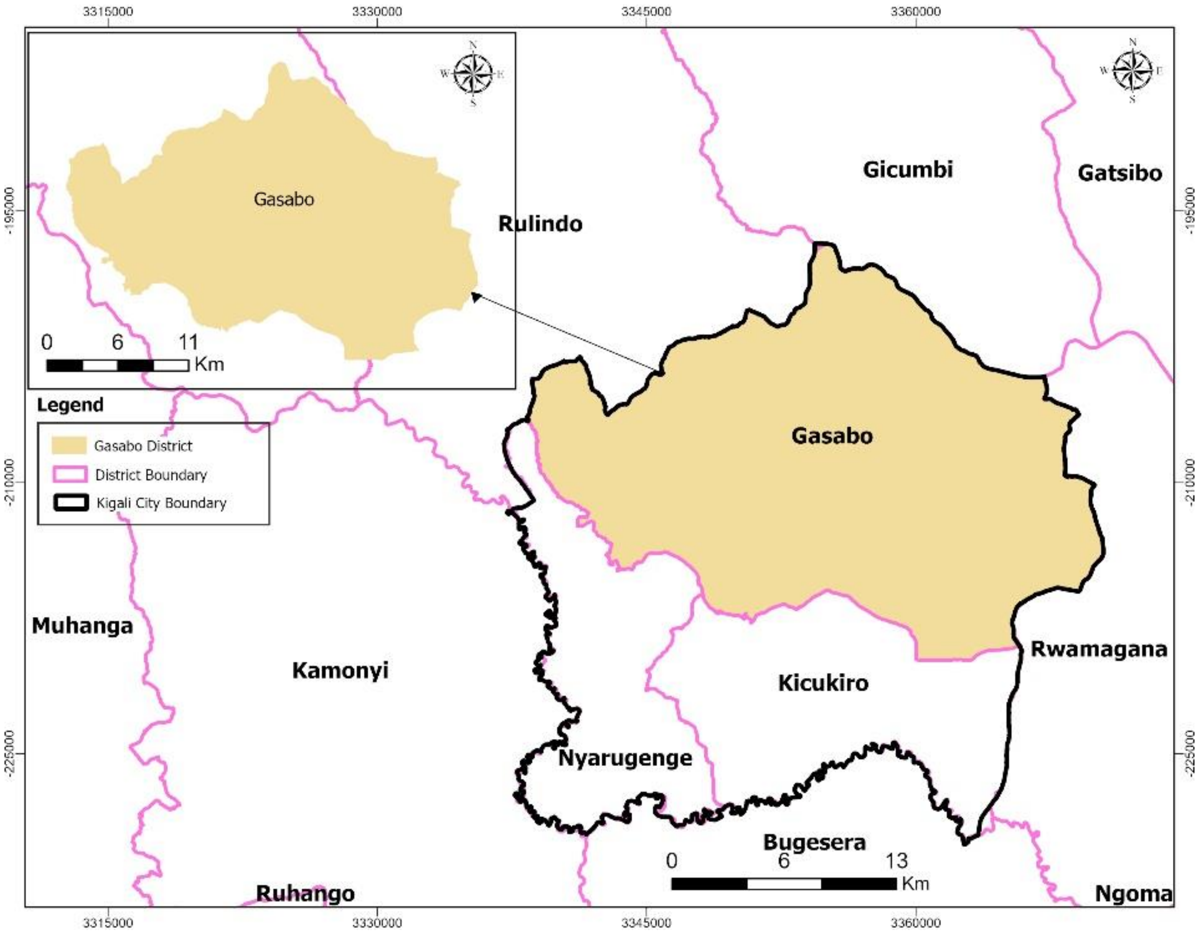
including: Bumbogo, Gatsata, Jali, Gikomero, Gisozi, Jabana, Kinyinya, Ndera, Nduba, Rusororo, Rutunga, Kacyiru, Kimihurura, Kimironko, and Remera (Yeenee et al., 2024). The district is an ideal case study for testing potential urban agriculture spaces. The area has a favourable climate with an average annual rainfall of 900-1,400 mm and moderate temperatures, making it an ideal location for agricultural activities, even in urban settings (Andreae, 2013). The study aimed to understand the potential of urban agriculture in the region due to its rapid urbanisation and limited land for food production.

Figure 1: Location of the Gasabo District in the City of Kigali.



Data Collection and Processing

The study utilised both primary and secondary data sources to comprehensively assess rooftops and wall-based urban agriculture for enhancing food security in the Gasabo District. This study examined urban agriculture in Gasabo District using household surveys, semi-structured interviews, field observations, and photographic documentation. It explored demographics, food access, agricultural practices, and perceptions of rooftop and wall farming. Key informants, government officials, urban planners, architects, and agricultural experts provided insights into policy frameworks, planning integration, technical feasibility, and sustainability. Fieldwork assessed crop types, farming methods, environmental and spatial issues, and building suitability. A detailed questionnaire measured food security, affordability, access, and coping strategies. Data analysis identified key trends, challenges, and opportunities for scaling urban agriculture in Kigali.

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The sampling design/technique is a systematic plan for selecting a portion of the population from a sampling frame (Heeringa et al., 2004). Specifically, 724,211 households in the Gasabo District. The researcher chooses the sample size to represent the total population, and it is calculated using Sloven's formula. This process ensures the collection of accurate and representative data.

n=N/1+N e2

Where n is the sample size, N is the total population corresponding to all urban residents of the Gasabo district, and e is the sampling error (0.05).

Therefore,

n=724211/1+724211(0.05)2

n=724211/1+724211(0.0025)

n=724211/1811.5275

n=399.7, approximately 400 households

The study used a stratified sample technique to select 400 household heads, ensuring precision in estimating population parameters (Dangi et al., 2008). The proportionate stratification approach calculated each sample size proportionate to the population size. Purposive sampling, also known as judgmental or selective sampling, was employed to select 15 key informants, ensuring the research adhered to specific standards relevant to the study's objectives. This method ensured the study's accuracy and reliability.

A pilot test was conducted on a questionnaire and interview guide to identify potential biases. To maintain uniformity, researchers coded a subset of data separately and compared their coding choices to ensure consistency. Triangulating data from multiple sources enhanced credibility and reliability. Reliability was assessed considering source, resolution, and limitations of spatial data. Knowledge from literature and expert knowledge was used to identify appropriate slope thresholds.

Secondary data was used to provide technical, policy, and spatial context for the study of Rwandan urban agriculture. This included Landsat 8 and Sentinel-2 images for LULC classification and rooftop/wall surface mapping, Digital Elevation Model (DEM), and Digital Surface Model (SRTM) for roof slope, aspect, and drainage capacity evaluation (Polidori, 2020), City of Kigali GIS unit building footprint data, Rwanda Agriculture Board (RAB) soil suitability maps, and Rwanda Meteorological Agency climate data. The study also consulted policy and documentation sources such as MINAGRI, FAO, UNDP, World Bank reports, Rwanda Vision 2050, National Strategy for Transformation, Kigali City Master Plan 2050, and National Agriculture Policy. Peer-reviewed scholarly publications provided methodological advice and comparative analysis from related urban agricultural projects worldwide.

The study evaluated the potential of urban gardening on walls and rooftops in Rwanda, using a case study approach that combined qualitative and quantitative data. The quantitative approach focused on spatial data analysis and descriptive statistics from field surveys. The qualitative method involved obtaining data from informants, while the quantitative method used spatial data and documentary review to evaluate the appropriate areas for rooftop and wall-based urban-farming techniques. The Gasabo District was chosen to provide a comprehensive understanding of urban agriculture in Rwanda.

The research involved designing an interview guide and questionnaire to comprehensively explore food security and urban agriculture in the region, utilising statistical tests and qualitative data analysis to ensure alignment with established theories and existing knowledge. The Content Valid Index (CVI) was utilised to verify data validity (Psihoda et al., 2022). With supervisors and an infrastructure performance evaluation expert receiving a copy of the form. Relevant questions were rated based on the total number of items, with the CVI calculated

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by dividing the number of experts rating each item by three or four.

The formula for calculating CVI is:

CVI="No. of items regarded relevant by judges" /"Total No. of items"

According to (Fallahzadeh et al., 2023), the CVI should be more than or equal to 0.7. The study assessed the accuracy of Landsat imagery-derived LULC classification using ground truthing and accuracy metrics, ensuring transparency in data processing and acknowledging limitations to ensure the results accurately reflect the urban agriculture potential in Gasabo.

Data Analysis

This section discusses the technical procedure for handling and analysing gathered data, which is divided into three main sections: qualitative data (interview data), quantitative data (survey data), and spatial data (RS and GIS data). The results from the questionnaire were prepared and analysed using SPSS, with the initial stage involving importing the data into IBM SPSS Statistics V.30 (Zhao et al., 2020). The data was checked for missing values and extreme values using box plots or z-scores. The study utilised numerical codes to convert qualitative responses into statistical data. Respondents were assigned numerical values for Likert scale responses, assigning 1 for "Yes" and 0 for "No." New variables were established by assigning numerical values to each response (Vogt et al., 2014). The data was analysed using coding, editing, and tabulation, ensuring accurate and reliable results.

For geospatial data processing, the study uses a systematic approach to evaluate the potential of rooftop and wall-based urban agriculture in Kigali's Gasabo District. The process involves collecting and pre-processing data from various sources, including Sentinel-2, Landsat 8, and high-resolution satellite imagery (Labib & Harris, 2018). High-precision data on building structures is obtained through aerial imagery. Light Detection and Ranging (LiDAR) data is used to extract three-dimensional data on building heights, rooftop structures, and wall orientations (Wang, 2013). The data is then converted into a Digital Surface Model (DSM) to accurately determine building elevation and identify rooftop surfaces.

The study uses Random Forest and ArcGIS Pro to classify surfaces of walls and rooftops for land use and land cover. It focuses on built-up areas for rooftop and wall-based agriculture (Steinicke, 2005). The findings are validated using the FAO-developed SEPAL platform. The study extracts information about rooftop area, slope, and orientation using ArcGIS's Object-Based Image Analysis (OBIA). It assesses wall appropriateness in Rwanda by determining building height and orientation, with south-facing walls providing the most solar exposure (DEL PERO & Manfren, 2014).

RESULTS

Roof and Wall Spaces Suitable for Urban Agriculture

Figure 2 shows the suitability of rooftops and walls for urban agriculture in the Gasabo District. 141,279 rooftops and walls are suitable for urban agriculture due to their flat or gently sloping roofs, adequate sunlight exposure, and access to water resources. These areas are concentrated in sectors with well-planned urban infrastructure, designed to accommodate additional loads and have reliable water sources. The spatial findings suggest that the suitability of wall and rooftop surfaces for urban agriculture varies across sectors in the Gasabo District, as shown in Figure 2. High suitability is found in Kinyinya and Ndera due to flat roofs, sunlight, and accessible water sources, making them ideal for early investment and pilot programs. Gikomero and Rutunga show poorer suitability due to structural limitations, steep roofing, or limited sunlight (Figure 3).

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Figure 2: Available roof and wall spaces suitable for urban agriculture.

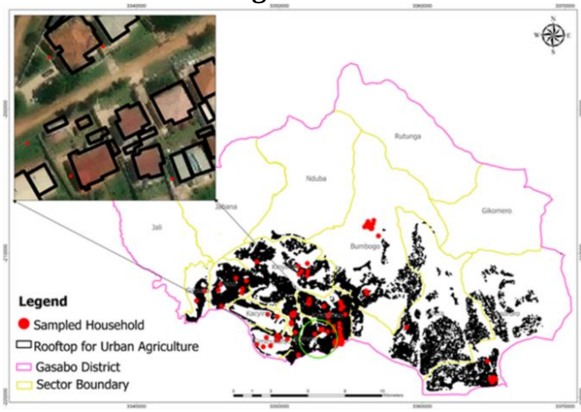
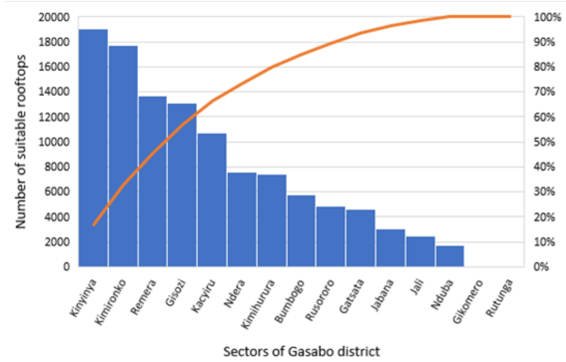


Figure 3: Variability of suitable spaces across sectors of the Gasabo District.



Challenges Affecting Rooftop and Wall Farming Potential

The Gasabo District's rooftop and wall farming faces challenges, including coping mechanisms, skipping meals, dietary diversity, and food access, as outlined in a survey and interviews, which limit its adoption and effectiveness.

Table 1: Household Food Security Challenges and Coping Strategies.

Indicator	Category	Frequency	Percentage (%)
Coping Strategies	Reduce the number of meals per day	62	20.88%
	Rely on cheaper, less nutritious foods	57	19.19%
	Borrow food or money	80	26.94%
	Sell assets (e.g., livestock, household items)	136	45.79%
	Rely on food aid (government, NGOs)	11	3.70%
	Other	10	3.37%
Skipping Meals Frequency	Never	163	54.88%
	Sometimes	110	37.04%
	Occasionally	13	4.38%
	Often	11	3.70%
Dietary Diversity	1-2 food groups	76	25.59%
	3-4 food groups	161	54.21%
	5 or more food groups	60	20.20%
Challenges in Accessing Food	Lack of money	169	56.90%
	Lack of food in the markets	101	34.01%
	Poor harvests	78	26.26%
	Other (e.g., lack of land, farming knowledge)	5	1.68%

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This study highlights five key challenges hindering the adoption of rooftop and wall farming in the Gasabo District. Structurally, 57.4% of respondents identified inadequate building integrity as a major barrier, while 63.3% cited a lack of knowledge and technical expertise, compounded by limited training programs and skilled labour. Financially, 47.9% of potential adopters lack the necessary resources due to insufficient support from financial institutions and government programs. Environmentally, 42.6% of households reported weather-related risks—such as strong winds, heavy rainfall, and high temperatures—as significant challenges, with 58.2% indicating that limited access to water and high irrigation costs further discourage participation. On the policy front, the absence of clear urban agriculture regulations, integration into building codes and zoning laws, and weak coordination among stakeholders severely limit implementation. Socially, 39.8% of respondents were unaware of rooftop and wall farming, with cultural attitudes, aesthetic concerns, and resistance from landlords further reducing engagement. Grounded in Land Use and Urban Resilience Theories, the study explores how urban spaces can be repurposed to enhance food security, income generation, and dietary diversity. It calls for integrated policy reforms, financial incentives, technical training, and cross-sector collaboration, drawing from successful models in cities like New York and Berlin to support the sustainable expansion of urban agriculture in Rwanda.

Current Status of Food Security in Gasabo District

Socio-economic Characteristics of Respondents

The study analysed demographic characteristics in the study area, including gender, age, income, land use, and ownership. The majority of respondents were middle-aged, with 36.36% earning between 50,000-100,000 RWF per month. Employment varied across sectors, with salaried jobs being the most common. Land ownership was high, with 67.68% owned by households; however, only 8.42% of this land was used exclusively for agriculture. Most households relied on market purchases, with limited homegrown food production. These socio-economic factors have a significant impact on household food security and urban agriculture practices.

Table 2: Socio-economic Characteristics of Respondents.

Characteristic	Categories	Percentage (%)
Gender	Male	63.97
	Female	36.03
Age Range (years)	Minimum: 26, Maximum: 87	-
	Average Age	52.8
Household Monthly Income (RWF)	Below 50,000	17.85
	50,000 - 100,000	36.36
	100,000 - 200,000	13.47
	Above 200,000	32.32
Primary Source of Income	Salary/Wages	39.39
	Small Business/Trade	18.86
	Agriculture (Farming/Livestock)	36.70
	Remittances	3.03
	Other	2.02
Land Ownership	Yes	67.68
	No	32.32
Land Use	Agricultural	8.42
	Residential	24.92
	Mixed Use	29.97

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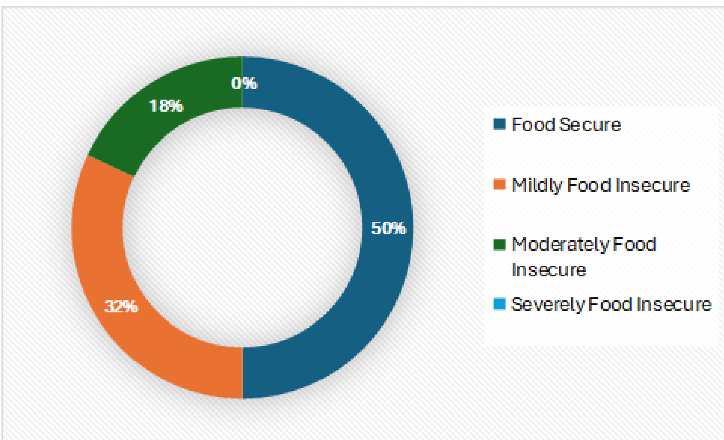
The study reveals that food security is a significant issue in urban areas, particularly in the Gasabo District. The survey reveals that households struggle to access nutritious food, highlighting challenges and coping mechanisms. Urban agriculture could be a potential solution to address this issue.

Table 3: Food Security Indicators.

Food security indicator	Never (%)	Occasionally (%)	Sometimes (%)	Often (%)
Difficulties in affording food (past month)	81.1	12.0	0.0	5.7
Going to bed hungry (past 12 months)	69.2	7.4	20.2	2.7
Skipping meals due to food shortage (past 12 months)	54.6	4.3	36.1	3.6
Eating less than needed due to food shortage (past 12 months)	56.9	4.3	36.6	2.0

The study shows that despite 69.2% of households never going hungry in the past year, over 30% experienced occasional to frequent hunger, and 45.4% skipped meals due to food shortages. This highlights the pressing issue of food insecurity, with only 50% of households being food secure, 32% being mildly, 18% moderately, and 0% severely food insecure.

Figure 4: Current Food Security Status in the Gasabo District.



Source: *Primary data, 2025.*

With these results, several factors influenced household food security in the Gasabo district (Figure 4). The study identified the following primary determinants: (1) income levels and market dependency, where 56.9% of households experiencing food insecurity cite lack of money as the primary reason, with households earning below 50,000 rwf per month being particularly vulnerable. High dependency on food markets, with 81.48% obtaining food through purchases, exacerbates food insecurity. (2) dietary diversity and nutritional quality, where food security is influenced by the availability of various food groups, but only 20.2% of households regularly consume five or more. High food prices and limited agricultural engagement limit access to fresh produce, contributing to lower nutrition levels. Households use coping mechanisms like reducing meals, relying on cheaper, less nutritious foods, and selling livestock. Reliance on food aid remains minimal, highlighting the need for sustainable solutions like urban agriculture. Food insecurity in the Gasabo district

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persists due to economic constraints, market dependence, and dietary diversity limitations, but urban agriculture, especially rooftop and wall-based, can improve household food security.

Correlation between Rooftop and Wall Agriculture and Food Security Enhancement

The adoption of rooftop and wall agriculture is low, with only 0.67% of respondents currently practising it. However, a survey shows a strong interest in urban farming as a solution to food security challenges. A positive correlation was found between willingness to adopt urban farming and food security enhancement, suggesting that households with better food security scores.

Table 4: Correlation between Willingness to Adopt Urban Farming and Food Security Enhancement.

	Willingness to adopt urban farming	Food security score
Willingness to adopt urban farming?	1	
Food security score	0.3	1

Regression analysis further explores this relationship, as summarised in Table 5. The regression model shows that willingness to adopt urban farming explains about 10.06% of the variation in food security scores ($R^2 = 0.1006$). The coefficient ($\beta = 0.267$) is statistically significant ($p < 0.001$), indicating that higher willingness to adopt urban farming is associated with improved food security levels.

Table 5: Regression Analysis.

Multiple R	0.32
R Square	0.10
Adjusted R Square	0.10
Standard Error	0.76
Observations	246

The adoption of rooftop and wall agriculture is low, with only 0.67% of respondents currently practising it. However, a survey shows a strong interest in urban farming as a solution to food security challenges. A positive correlation was found between willingness to adopt urban farming and food security enhancement, suggesting that households with better food security scores.

DISCUSSION

The section analyses the study's findings concerning existing research on food security and urban agriculture, focusing on comparisons with earlier research, theoretical and empirical contributions, and policy implications for urban planning. The findings of the research are consistent with important ideas in the literature on food security and urban agriculture. For instance, the finding that rooftops and wall spaces are suitable for farming is consistent with data from places like Nairobi, Kenya, and New York City, USA, where underutilized urban surfaces have been effectively used for growing food GIS and remote sensing methods are used to assess rooftop suitability in Rwanda, aligning with research by (Kimote, 2020). However, most Rwandans have not yet adopted wall-based and rooftop urban gardening, particularly in the Gasabo District. Unlike other regions, Rwanda has limited research on vertical approaches, with most studies focusing on backyard and peri-urban agriculture. This highlights the need for more comprehensive urban farming strategies.

This study explores the potential of vertical farming systems like hydroponics, container gardening, and vertical grow towers in Kigali, addressing constraints like space, soil depth, and weight-

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bearing capacity, aligning with research done by Taguchi and Santini (2019). Despite identifying over 141,000 suitable rooftops, none of the respondents currently engage in rooftop or wall-based agriculture, highlighting the novelty of this approach in Kigali urban areas. The study explores the potential of Systems Theory, Sustainable Livelihoods Framework, and Urban Resilience Theory in urbanised African regions, correlated with research done by (Romero-Lankao et al., 2016). It highlights the potential for scaling up food production, even in low usage situations. The study also shows a positive correlation between readiness to adopt urban agriculture and household food security ratings. The GIS-based mapping of wall and rooftop potential demonstrates how Land Use Theory can be applied in contemporary, space-constrained urban settings. Gasabo's rooftops meet the requirements.

This disconnect between suitability and actual adoption can be attributed to several interrelated barriers. First, widespread lack of awareness and technical knowledge, reported by 63.3% of respondents, has limited the population's familiarity with rooftop and wall-based systems, especially hydroponics and vertical gardens (Taguchi & Santini, 2019). Second, financial constraints remain a major bottleneck, with 47.9% of potential adopters citing insufficient capital to cover initial investment and maintenance costs, particularly in the absence of targeted subsidies or microcredit (Nzeyimana, 2021). Third, policy and institutional gaps, such as unclear building codes and a lack of supportive zoning regulations, discourage landlords and residents from experimenting with these systems (Gakuba, 2024). Finally, social and cultural perceptions, including aesthetic concerns and scepticism from property owners, reduce uptake in densely populated areas. These barriers underscore the importance of targeted awareness campaigns, technical training, and a robust policy framework to unlock the full potential of vertical agriculture in Kigali, aligning with urban resilience strategies adopted in cities like Nairobi and New York (De Zeeuw et al., 2017; Khan et al., 2020).

Urban agriculture planning should be tailored to the local context and physical infrastructure, with interventions focusing on areas with optimal structural conditions. GIS-based analysis and survey data can help identify suitable areas for lightweight hydroponic systems and large-scale rooftop gardens, aligning with research (Montealegre et al., 2022). This helps prioritise policy, investment, and technical training, identifying opportunity zones for Kigali's rooftop and wall-based urban farming policy agenda.

The study suggests integrating urban agriculture into Kigali's urban planning agenda by piloting rooftop and wall farming in high-suitability sectors like Kinyinya and Ndera. Technical support, water harvesting innovations, and hydroponic system training could catalyse adoption. Awareness campaigns, subsidies, and demonstration projects could catalyse action. The study recommends that architects and planners assess load-bearing capacities and develop safety guidelines for retrofitting buildings with farming infrastructure. In conclusion, this study provides the first empirical, GIS-supported mapping of rooftop and wall-suitability for urban agriculture in Rwanda, coupled with household-level food security data. The identification of over 141,000 viable structures, combined with a strong positive correlation between adoption and food security ($r = 0.3$), offers a critical evidence base for integrating vertical agriculture into Kigali's urban planning. While no formal policies exist yet, these findings serve as an essential starting point for initiating discussions, pilot projects, and investment frameworks aimed at food resilience and spatial sustainability.

CONCLUSION

The study addressed three main research objectives, each yielding significant insights: The GIS and remote sensing analysis revealed that rooftops and walls in the Gasabo District have significant

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potential for urban agriculture. Approximately 32% of rooftops and walls were identified as suitable for farming, with clear spatial variability across sectors, particularly in Kinyinya and Ndera, which offer high structural suitability. Factors such as structural capacity, sunlight exposure, and water access were critical in determining suitability. Moreover, the household surveys indicated that 50% of households in the Gasabo District are food secure, while 32% are mildly food insecure, and 18% are moderately food insecure. Key challenges include high food prices, market dependency, and limited access to fresh produce. Urban agriculture was found to positively influence food security, with households engaged in farming reporting higher dietary diversity and reduced food expenditures. Finally, the study found a positive correlation (r = 0.3) between the adoption of rooftop and wall-based agriculture and improvements in food security. Regression analysis showed that willingness to adopt urban farming explains 10.06% of the variation in food security scores, highlighting its potential as a viable strategy for enhancing food security.

This study, therefore, demonstrates that urban agriculture in the Gasabo District presents a viable pathway to enhancing food security among urban residents. The untapped potential of rooftop and wall structures represents a significant opportunity for expanding food production within the urban environment. The correlation between urban agriculture adoption and improved food security, though modest, suggests that rooftop and wall farming can contribute meaningfully to addressing food insecurity challenges. By utilising existing urban infrastructure for food production, households can increase their access to fresh produce, enhance dietary diversity, and reduce food expenditures, all critical components of food security. Given the marked spatial variability and structural differences across sectors, targeted and sector-specific interventions, particularly in high-potential areas like Kinyinya and Ndera, are essential for effective implementation. While urban agriculture alone may not completely resolve food insecurity in the Gasabo District, it can be an effective component of a comprehensive food security strategy. Further research and policy support are needed to address implementation challenges, maximise adoption rates, and fully realise the potential of urban agriculture in enhancing food security in Rwanda's urban centres.

Future research should focus on identifying suitable crops for rooftop and wall farming in Rwanda's tropical highland climate, while also assessing the economic viability and sustainability of hydroponic systems and vertical gardens for low-income households. Additionally, studies should evaluate the long-term social, environmental, and economic impacts of urban agriculture initiatives, exploring water-efficient technologies and the integration of green roofs into public infrastructure.

Conflict of Interest

The authors declare no known conflict of interest

Ethic Statement

This research was conducted in accordance with ethical standards. No human subjects or animals were involved in this study, and no ethical approval was required for this type of research.

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