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Abstract

This study investigates the impact of urbanization on community perceptions of climate-related risks in Nyarugenge District, Kigali, Rwanda. Urban expansion often exacerbates vulnerabilities to hazards such as flooding and heat stress, particularly in informal settlements. The problem arises from a lack of empirical research on how urbanization influences local perceptions and responses, leading to ineffective adaptation strategies. The primary objectives include assessing the extent and patterns of urbanization, analysing community perceptions of climate risks, and exploring their relationship. A mixed-methods approach was employed, utilizing quantitative surveys and qualitative interviews with 388 respondents. Key findings indicate that individuals in flood-prone areas perceive risks as more imminent, with a mean score of 4.60 (SD = 0.596). Education and awareness campaigns are crucial for shaping perceptions, receiving a mean score of 4.53 (SD = 0.720). Low-income households often reside in high-risk areas due to affordability constraints, with a mean score of 4.79 (SD = 0.652). Conversely, higher-income individuals are more likely to invest in adaptive measures, reflecting socio-economic disparities. Recommendations include enhancing infrastructure in informal settlements, promoting education initiatives, strengthening economic support mechanisms, and improving access to early warning systems. These strategies aim to foster resilience and ensure that adaptation efforts are inclusive and effective for all community members.

Keywords: *Urbanization, climate risks, community perceptions, Nyarugenge District, resilience, socio-economic disparities, adaptation strategies.*

1. Introduction

A well-planned urbanization in Nyarugenge District, Kigali, would lead to economic development while reducing exposure to climate-related disasters like floods, landslides, and heat stress. Well-designed urban development would incorporate resilient infrastructure, efficient drainage systems, and community-based adaptation initiatives. These adaptations would safeguard livelihoods, lessen the severity of climate-related

incidents, and promote the well-being of all inhabitants, including those in informal settlements (Mwenje & Kumar, 2024). But the situation in Nyarugenge District is contrary, as urbanization has aggravated the urban heat island phenomenon and the frequency including the magnitude of climate-related risks. Informal settlements are among the most susceptible because of inadequate infrastructure, scarce access to essential services, and socioeconomic disparities, which render inhabitants less adaptable to environmental threats (Niyomugabo et al., 2022; Kalisa et al., 2021). Poor drainage systems and uncontrolled land use lead to frequent floods and landslides that damage houses, disrupt livelihoods, and heighten public health hazards. Although the government has introduced programs such as the Green Growth and Climate Resilience Strategy, adaptation initiatives tend not to include local knowledge, which is essential in fostering community-led climate resilience (Monteiro et al., 2022).

A key challenge in Nyarugenge District is the lack of empirical study on residents' perception related to climate hazards. Adaptation policies are likely to be a product of top-down planning with minimal involvement of individuals, portending ineffective measures that ignore contexts and worsen inequalities (Buchenrieder et al., 2021). For instance, current interventions, including drainage upgrading and resettlement policies, have failed to minimize community vulnerabilities and tackle underlying drivers of climate risks (Niyomugabo et al., 2022). Empirical research shows that community participation and participatory governance are essential for successful climate adaptation (Owusu & Afutu-Kotey, 2010; Isunju et al., 2016). Likewise, highlight the need to take social and economic considerations into account while formulating adaptation measures (Fragkou & McEvoy, 2016; Revi et al., 2014). Nevertheless, such people-oriented strategies are underdeveloped in Nyarugenge District, where social, economic, and infrastructural determinants of climate risk perception are usually neglected in policy formulation.

This study aimed to assess the impact of urbanization on climate risk perception in Nyarugenge District. It examined how population growth, informal settlements, infrastructure development, land use change, and housing conditions influence these perceptions. It also identified barriers to effective adaptation. Through incorporating local perspectives, the research seeks to shape participatory climate policy in accordance with Rwanda's Vision 2050 for urbanization, which aims to bolster urban resilience and make adaptation solutions effective and equitable.

1.2 Objectives of the Research

1.3 General Objective

The general objective of the study is to assess the impact of urbanization on community perceptions of climate-related risks in Nyarugenge District, Rwanda, and provide insights to inform inclusive and sustainable adaptation strategies.

1.4 Specific objectives

(i) To analyze the extent and patterns of urbanization in Nyarugenge District.
(ii) To assess community perceptions of climate risks in Nyarugenge District.
(iii) To examine the relationship between urbanization and community perception of climate risks in Nyarugenge District.

2. Materials and methods

2.1 Profile of the study area

Nyarugenge District, one of the three districts of Kigali Province, covers about 133.9 square kilometers and serves as the capital's main commercial and administrative hub. According to the 2022 census, it has a population of 374,319 and a density of 2,796 people per square

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kilometer, divided into ten sectors including Kigali, Mageragere, Kimisagara, and Nyamirambo. Rapid urbanization has intensified environmental challenges such as flooding, urban heat islands, and unequal infrastructure distribution, heightening vulnerability in low-income areas.

Although Rwanda's Green Growth and Climate Resilience Strategy addresses climate challenges, little empirical data exists on how urban residents perceive and respond to climate risks. Understanding these perceptions is essential for designing locally appropriate adaptation strategies. This study aims to fill that gap by examining how urbanization influences community-level climate risk perceptions in Nyarugenge, ultimately supporting fair, effective, and inclusive climate resilience and sustainable urban development in the district.

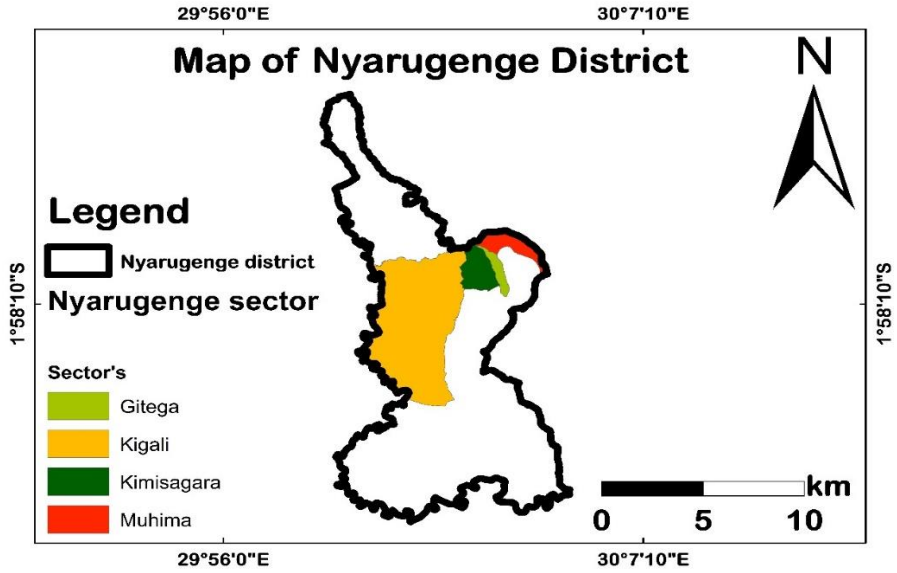

Figure 3.1: Map of Nyarugenge District, case study (Gitega, Kigali, Kimisagara, & Muhima sectors)

Source: designed by researcher using GIS Software (Arc MAP, 2025)

The map of Nyarugenge District highlights the central and densely urbanized sectors of Gitega, Kigali, Kimisagara, and Muhima in the heart of the district. These have high population densities, are highly characterized by informal settlements, and are a place of concentration of economic activities. Gitega is located northern-centrally in the district and is generally a residential area with informal settlements and some commercial activities.

Kigali falls to the northeast of the district, encompassing parts of the Central Business District with its administrative offices and major infrastructures. Kimisagara lies to the northwest of the district Characterized by hilly slopes and highly densely packed informal housing. Muhima lies to the northeast of Kimisagara and west of the Kigali Sector Has Nyabugogo Bus Park, acting as the commercial and transit hub. The targets for this study are sectors interconnected by major roads and transport networks; the important fact that makes them relevant to the study their proximity to the central business area. Their nature of urbanization challenges like flooding, informal housing, and disparities in resource allocation make them ideal for the analysis of community perceptions of climate risks.

2.2 Research design and data collection methods

This study adopted a descriptive research design using a mixed-methods approach to analyze how urbanization affected community perceptions of climate risks in Nyarugenge District. The target population consisted of 167,244 residents from four urban sectors—Gitega, Kigali, Kimisagara, and Muhima—including 167,232 households and 12 urban planner staff. Using Sloven's formula, a sample size of 400 respondents was determined. Stratified sampling was applied to households, while purposive sampling targeted urban planners.

Quantitative data were collected through structured household questionnaires and secondary sources to assess demographics, socioeconomic factors, and climate risk perceptions. Qualitative data were obtained through focus group discussions with women, youth, and urban poor, key informant interviews with policymakers and planners, and field observations of infrastructure and environmental conditions. The data were analyzed using statistical and thematic techniques, and triangulation ensured validity and provided a comprehensive understanding of urbanization's impact on climate risk perception.

2.4 Data analysis

Data were analyzed using a mixed-method approach integrating quantitative and qualitative techniques to understand how urbanization affected perceptions of climate risks in Nyarugenge District. GIS analysis was used to assess urbanization levels, while SPSS processed quantitative data from structured questionnaires. Descriptive statistics (frequencies, percentages, and means) summarized demographics and perceptions, and correlation, regression, and cross-tabulations explored relationships between urbanization factors and climate risk perceptions.

Qualitative data from interviews, focus groups, and field observations were analyzed thematically through coding and categorization to identify patterns and community narratives. Triangulation of multiple data sources enhanced validity and ensured consistency between quantitative and qualitative findings.Validity was confirmed through expert review, pilot testing, and a Content Validity Index (CVI $\geq$ 0.60), while reliability was tested using Cronbach's Alpha ($\geq$ 0.70). Ethical principles included informed consent, confidentiality, voluntary participation, cultural sensitivity, and ethical clearance from relevant boards, ensuring fairness and participant protection throughout the study.

3. Results

The study found that occupation, education level, length, and type of residence significantly affect climate resilience in Nyarugenge District. Most respondents engaged in business and had higher education, enhancing their capacity to adopt climate adaptation measures. Long-term residents showed greater awareness of local environmental issues. However, those in informal settlements faced higher vulnerability due to poor infrastructure and flooding risks. The study recommends targeted interventions in informal areas, climate education, and sectoral support to strengthen overall resilience.

3.1 To analyze the extent and patterns of urbanization in Nyarugenge District

The qualitative data gathered from interviews with urban planners, district officers, and community leaders in Nyarugenge District offers valuable insights into the relationship between urbanization, climate-related risks, and community perceptions. Urbanization has significantly influenced climate risks, particularly flooding and heat stress, as noted by urban planners who highlighted the increase in impervious surfaces that reduce natural

water absorption, leading to heightened flood risks. Informal settlements, lacking adequate drainage systems, are particularly vulnerable to flooding during heavy rains. Additionally, high population density exacerbates the urban heat island effect, increasing energy consumption and emissions, which necessitates urgent attention to infrastructure and land-use planning.

Various urban planning strategies aimed at mitigating these climate risks have been discussed, including integrating green spaces into urban projects and restoring wetlands. However, challenges persist, such as slow implementation, inconsistent compliance with green building standards, and limited funding for large-scale adaptation projects. District officers emphasized the importance of upgrading drainage systems and improving solid waste management to prevent flooding, yet the effectiveness of government-led initiatives like the Green Growth and Climate Resilience Strategy is hindered by inconsistent enforcement and community resistance to relocation efforts.

Community awareness regarding climate risks is growing, particularly among residents of informal settlements who directly experience climate impacts. However, there remains a gap in understanding the long-term implications of climate change, with many residents viewing it as a natural cycle rather than an urgent concern. Public participation is essential in urban planning and climate adaptation strategies, yet the disconnect between community members and decision-making processes can lead to resistance against proposed solutions, complicating adaptation efforts.

Key environmental concerns linked to rapid urbanization include increased flooding, heat stress, deteriorating air quality, and loss of biodiversity. The district's integration of climate resilience into urban development plans is evident, with policies encouraging green building practices and the protection of wetland areas. Nonetheless, challenges in enforcing these regulations and ensuring compliance among developers remain. There is a recognized need for stronger coordination among government agencies, private sectors, and NGOs to implement effective climate resilience measures.

To enhance urban resilience against climate risks, several recommendations emerge from the interviews, including strengthening enforcement of land-use regulations, increasing investment in climate-resilient infrastructure, expanding green spaces, and providing incentives for sustainable construction practices. Improving public awareness campaigns and community engagement initiatives could foster a deeper understanding of climate risks and encourage proactive adaptation measures. Overall, the insights from the interviews underscore the need for a collaborative approach to effectively address the intertwined challenges of urbanization and climate change in Nyarugenge District.

3.1.2. Population growth and density.

The table6. detailing the population distribution in Nyarugenge District, based on the 2012 Population and Housing Census, reveals significant insights into population growth and density. With a total population of 284,561, the district exhibits a nearly balanced gender ratio, which is crucial for understanding future demographic trends.

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Table 3.1: Distribution (count) of the resident population of 4 sectors in Nyarugenge district

sector	both sexes	Male	Female	Female %	population share (% of the total population)	Density (inhabitants/km2)
Gitega	28728	14989	13739	47.8	10.1	24,482
Kimisagara	29768	17222	12925	42.1	10.5	10,589
Kigali	30023	15375	14648	48.8	10.6	1022
Muhima	29768	17222	12546	42.1	10.5	10115

Source: fifth Rwanda population and housing census 2022

The population is unevenly distributed across sectors, with the Kigali Sector housing the highest number of residents (28,789), reflecting urbanization patterns where urban areas attract more inhabitants. High population density in these sectors indicates substantial pressure on housing, services, and infrastructure, often leading to the expansion of informal settlements. This aligns with the average national density of 415 inhabitants per square kilometer, highlighting the challenges associated with resource allocation and service provision in densely populated areas. The implications of such density can be twofold; while it can foster economic activities and improve access to services, it can also exacerbate overcrowding and inadequate living conditions, making populations more vulnerable to climate-related risks. These trends resonate with urbanization theories that emphasize the relationship between population growth and urban development, suggesting that effective urban planning is essential to accommodate growth while ensuring equitable access to resources. Overall, the data underscores the need for sustainable urban development strategies in Nyarugenge District to address the complexities of urbanization and enhance community resilience.

Table 3.2: Distribution (Count and %) of resident population of Nyarugenge district sector and area of resident in 2022

Sector	Counts			Percentage		
	Total	urban	Rural	Total	urban	Rural
Gitega	26668	26668		100	100	
Kimisagara	56534	56534		100	100	
Kigali	61499	44185	17314	100	71.8	28.2
Muhima	22531	22531		100	100	

Source: fifth Rwanda population and housing census 2022

The demographic data from Nyarugenge District, particularly in sectors like Kigali, Gitega, Kimisagara, and Muhima, has significant implications for community perceptions of climate risk. High population density in areas such as Kigali, with 266,680 residents, places intense pressure on infrastructure and housing. This overcrowding can exacerbate inadequate living conditions and limit access to essential services such as sanitation and drainage, leading residents to perceive climate risks like flooding or heatwaves as more immediate and severe. The rapid urban expansion also results in infrastructure challenges,

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particularly in sectors like Gitega (130,026 residents) and Kimisagara (133,575 residents), where the demand for services often outstrips supply. Insufficient drainage systems can increase vulnerability to climate hazards, fostering a belief among residents that local authorities are ill-equipped to manage these challenges, which can heighten anxiety about climate impacts. Additionally, the economic pressures associated with urban concentrations draw migrants seeking better livelihoods, often leading to informal settlements where residents lack secure land tenure and adequate services. In these contexts, the perception of climate risk is intensified, as individuals in informal housing may feel particularly susceptible to eviction or displacement due to climate events. In densely populated areas like Muhima (138,220 residents), community engagement becomes crucial; while high density can foster stronger networks for collective action, feelings of marginalization may lead to mistrust in governmental responses to climate risks. Overall, the interplay between urbanization and climate risk perception is complex, with residents increasingly recognizing climate change as a significant threat. This awareness can drive advocacy for better infrastructure and services, but if concerns remain unaddressed, it may foster fatalism regarding climate risks. Therefore, it is essential for local governments to prioritize infrastructure development and engage communities in climate adaptation efforts to cultivate resilience in the face of ongoing climate challenges.

3.1.3. Expansion of informal settlements

The descriptive statistics further highlight key challenges associated with informal settlements in Nyarugenge District, particularly their vulnerability to climate hazards. Poor infrastructure, such as inadequate drainage systems, contributes to increased exposure to climate risks, as evidenced by a mean score of 3.63 and a standard deviation of 0.723.

Table 3.3: Expansion of informal settlements

	A		SA		N		D		SD		Mean	Std. Deviation
	F	%	F	%	F	%	F	%	F	%		
Poor infrastructure in these areas, such as inadequate drainage systems, increases residents' exposure to climate hazards.	295	74.7	0	0	51	12.9	35	8.9	7	1.8	3.63	.723
Many informal settlements are located in high-risk areas such as flood-prone zones and steep slopes.	302	76.5	51	12.9	19	4.8	16	4.1	0	0	4.00	.588
The lack of formal planning makes adaptation strategies difficult to implement.	198	50.1	165	41.8	15	3.8	10	2.5	0	0	4.34	.675
Informal settlements in Nyarugenge are expanding due to rural-urban migration and high housing costs.	163	41.3	218	55.2	7	1.8	0	0	0	0	4.54	.534

Source: primary data 2025

This finding aligns with studies showing that many informal settlements lack basic infrastructure, leading to increased susceptibility to flooding, landslides, and other environmental hazards (Satterthwaite et al., 2020). Effective drainage and flood control

systems are critical in reducing climate-related risks, yet many unplanned urban areas lack these essential features (Mukamana & Nkurunziza, 2023).

Another significant factor is the location of informal settlements. The study found that many of these settlements are situated in high-risk areas, such as flood-prone zones and steep slopes, with a mean score of 4.00 and a standard deviation of 0.588. This result supports previous research indicating that informal settlements are often developed on marginal lands due to the lack of affordable housing options in safer areas (Alam et al., 2022). As urban populations grow, particularly through rural-urban migration, land scarcity forces low-income residents to settle in environmentally vulnerable locations (Revi et al., 2020).

The study also highlights the impact of the lack of formal urban planning on adaptation efforts. The mean score of 4.34 for the statement that the lack of formal planning makes adaptation strategies difficult to implement suggests strong agreement among respondents. This aligns with findings from Ziervogel et al. (2022), who argue that informal settlements often develop outside regulatory frameworks, making it challenging for authorities to introduce climate adaptation measures such as resilient housing construction, disaster risk management, and urban greening initiatives. Without proper planning, even well-intended climate resilience projects face obstacles in execution (Moser et al., 2021).

Additionally, the expansion of informal settlements in Nyarugenge is driven by rural-urban migration and high housing costs, as indicated by the highest mean score (4.54, SD = 0.534). This supports research emphasizing the economic drivers of informal settlement growth, where the high cost of formal housing and limited access to affordable alternatives push low-income residents into informal housing solutions (Ajibade, 2022). According to Rwanyiziri & Mukandaza (2023), Rwanda's urbanization trends reflect broader patterns seen in developing countries, where rapid migration into cities outpaces formal housing development, leading to increased informal settlements.

These findings reinforce existing theoretical perspectives, particularly the Sustainable Livelihoods Approach (Chambers & Conway, 2020), which suggests that access to infrastructure, secure housing, and economic stability are crucial in reducing climate vulnerability. The Climate Risk Perception Model (van der Linden, 2021) also applies, as it explains how residents' exposure to climate hazards influences their perception of risk and willingness to engage in adaptive strategies.

In conclusion, the descriptive statistics demonstrate that informal settlements in Nyarugenge face significant climate risks due to poor infrastructure, high-risk locations, and a lack of formal planning. The rapid expansion of these settlements, driven by economic and demographic pressures, further complicates adaptation efforts. These findings emphasize the need for integrated urban planning policies that promote climate-resilient infrastructure, affordable housing, and proactive adaptation measures to mitigate climate-related risks in vulnerable urban communities.

3.1.4 Urban infrastructure development

To interpret and analyze the map depicting land use and land cover (LULC) changes in Nyarugenge District from 2010 to 2025, we can observe several key trends that highlight the impact of urbanization on community perceptions and conditions.

The map illustrates two distinct periods: LULC in 2010 and projected LULC in 2025. Areas marked in yellow represent "built-up" regions, while the brown areas indicate "non-built up" land. A significant increase in the yellow areas can be observed from 2010 to 2025,

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suggesting substantial urban development and expansion of built environments, which often correlate with informal settlements.

The growth of built-up areas likely includes the proliferation of informal settlements, where housing is often constructed without proper regulations or infrastructure. Such areas typically emerge due to rapid urbanization, driven by urban migration and the inability of formal housing markets to meet demand (UN-Habitat, 2020). This trend raises concerns about the living conditions in these settlements, as they may lack essential services and infrastructure, making residents more vulnerable to climate-related risks (Baker et al., 2019). The transformation from non-built to built-up land suggests ongoing urban infrastructure development. Improved infrastructure can enhance connectivity and access to services but may also lead to displacement of existing communities and increased pressure on resources (Mastrorillo et al., 2016). This development needs to be managed carefully to ensure equitable access for all community members, particularly in informal settlements.

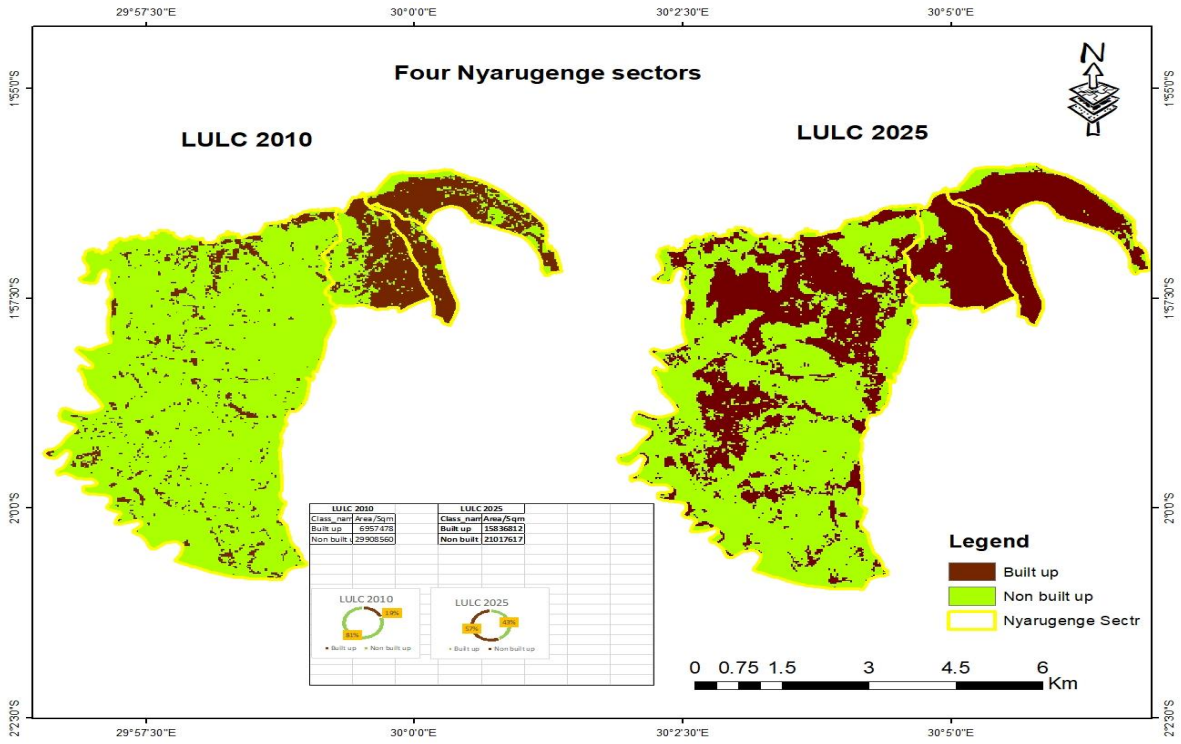

Figure 4.2: Urban expansion map of four sectors in Nyarugenge district (2010-2025)

Source: GIS map 2025

The increase in built-up areas indicates significant land use changes, where agricultural or green spaces are often converted into residential or commercial zones. Such changes can disrupt local ecosystems and diminish biodiversity, as noted by Seto et al. (2012). Furthermore, these land use alterations can exacerbate urban heat effects and increase vulnerability to flooding, especially in areas with insufficient drainage systems (Torras et al., 2018).

The quality of housing in newly developed areas, particularly informal settlements, often falls short of standards, leading to precarious living conditions (World Bank, 2021). This deterioration can further influence community perceptions of climate risks, as inadequate

housing increases susceptibility to environmental hazards. The presence of inadequate infrastructure in these settlements often results in limited adaptive capacity to cope with climate-related challenges (IPCC, 2021).

The findings align with urbanization theories that highlight the dual impact of growth: while it can lead to economic opportunities and improved infrastructure, it also risks exacerbating inequalities and vulnerabilities (Castells, 2010). The "urbanization of poverty" concept illustrates how urban expansion often sidelines low-income populations, pushing them into informal settlements where they face heightened risks (Burgess, 2000).

In conclusion, the map of Nyarugenge District illustrates significant changes in land use and cover from 2010 to 2025, reflecting the complex dynamics of urbanization. The expansion of informal settlements, infrastructure development, and changing land uses highlight the urgent need for integrated urban planning that prioritizes equitable access to resources and addresses the vulnerabilities of marginalized communities. Future policies must focus on improving housing conditions and resilience to climate-related risks, ensuring that all residents can benefit from urban growth.

3.1.5. Housing conditions

The findings from the descriptive statistics align closely with existing literature on urbanization and climate risk perception. Urbanization significantly influences how communities perceive climate risks, as it determines their exposure to environmental hazards. Research indicates that well-planned urban development reduces environmental risks, while unregulated expansion increases vulnerability (Revi et al., 2020). The study's high mean score (4.45) for the statement that well-planned housing with climate-resilient materials can reduce exposure to environmental hazards supports this argument. Studies have shown that cities with well-structured housing and resilient infrastructure experience fewer climate-related disasters (Nguyen et al., 2021).

Informal settlements remain particularly vulnerable to climate risks. The study found that poor housing structures in informal settlements are highly susceptible to extreme weather events, with a mean score of 4.47 and a standard deviation of 0.694. This finding aligns with existing research highlighting how low-income urban populations face disproportionate exposure to climate hazards due to inadequate housing (Satterthwaite et al., 2020). Many informal settlements lack basic infrastructure such as drainage systems, making them prone to flooding and heat stress (Mukamana & Nkurunziza, 2023). Additionally, social and economic constraints prevent residents from investing in climate-resilient improvements, further exacerbating their vulnerability (Alam et al., 2022).

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Table 3.4: Housing conditions

	A		SA		Mean	Std. Deviation
	F	%	F	%		
Well-planned housing with climate-resilient materials can reduce exposure to environmental hazards.	170	43.0	21	153.4	4.45	.768
Poor housing structures in informal settlements are highly vulnerable to extreme weather events.	170	43	21	153.4	4.47	.694
The quality of housing influences residents' perception of climate risks those in fragile structures may feel more threatened.	170	43.0	21	153.4	4.48	.687
Government policies promoting affordable, climate-resilient housing can enhance urban dwellers' adaptive capacity.	170	43.0	21	153.4	4.51	.599
Valid N						

Source: primary data 2025

Housing quality also plays a crucial role in shaping residents' perceptions of climate risks. The study reported a mean score of 4.48 for the statement that residents living in fragile housing structures feel more threatened by climate risks. This finding aligns with Moser et al. (2021), who argue that individuals in poor-quality housing perceive higher levels of climate risk due to their direct exposure to environmental threats. Similarly, Ajibade (2022) found that households experiencing frequent infrastructural damage from climate events, such as floods and strong winds, tend to have heightened anxiety about future disasters. The built environment, therefore, serves as a key determinant of climate risk perception, influencing how communities prepare for and respond to environmental challenges.

Government policies promoting affordable and climate-resilient housing play a crucial role in enhancing urban dwellers' adaptive capacity. The highest mean score (4.51, SD = 0.599) in the study supports the argument that strong policy interventions improve resilience. Research highlights that policies focusing on climate-adaptive urban planning, subsidized resilient housing, and infrastructure development significantly reduce urban vulnerability (Ziervogel et al., 2022). In Rwanda, initiatives aimed at upgrading informal settlements and integrating climate resilience into housing policies have proven effective in reducing climate risks for urban communities (Rwanyiziri & Mukandaza, 2023). Policy-driven adaptation measures, such as zoning regulations and housing subsidies, are essential for reducing the exposure of vulnerable populations to climate hazards.

The study's findings align with key theoretical perspectives, particularly the Sustainable Livelihoods Approach (Chambers & Conway, 2020), which emphasizes the importance of social, financial, and infrastructural assets in reducing vulnerability. Additionally, the Climate Risk Perception Model (van der Linden, 2021) suggests that individuals' risk perceptions are influenced by direct experiences, social context, and policy interventions. The data reinforce these theories, showing that individuals in poor housing conditions perceive greater climate risks, while those benefiting from government interventions feel more secure.

While this study provides valuable insights, some gaps remain in understanding the long-term impact of urbanization on climate risk perception. Future research should explore the

effectiveness of specific policy interventions and assess how changing urban conditions influence risk perception over time. Longitudinal studies could provide a deeper understanding of how climate adaptation strategies evolve in rapidly urbanizing districts like Nyarugenge.

3.1.6. Land use change

The land use and land cover (LULC) maps illustrate significant urban expansion in four sectors of Nyarugenge District Gitega, Kigali, Muhima, and Kimisagara between 2010 and 2025. In 2010, non-built-up areas dominated the landscape, while built-up areas were relatively limited to certain pockets. However, by 2025, there is a clear increase in built-up areas, particularly in the northern and central parts of the district. This transformation is indicative of rapid urbanization, driven by factors such as population growth, rural-urban migration, infrastructure development, and economic activities (Nsengimana et al., 2023).

Gitega and Kimisagara have experienced a surge in informal settlements due to high land costs and limited affordable housing. Many migrants seeking employment in Kigali settle in these areas, leading to unstructured urban growth. The expansion of informal settlements often results in inadequate infrastructure, such as poor drainage systems and weak housing structures, making these communities highly vulnerable to climate-related hazards like flooding and landslides (Uwizeyimana et al., 2021). In contrast, Kigali and Muhima, which serve as administrative and commercial hubs, have witnessed a more structured urban growth pattern. However, this has come at the cost of reduced green spaces, increased land pressure, and environmental concerns such as the urban heat island effect and air pollution (Nkurunziza & Habimana, 2023).

The implications of land use changes in Nyarugenge District are multifaceted. On the one hand, urban expansion has contributed to economic growth by increasing commercial activities, improving transportation networks, and creating employment opportunities. On the other hand, it has also led to environmental challenges, including deforestation, loss of biodiversity, and increased exposure to climate risks (Rwanyiziri & Mukandaza, 2023). The loss of non-built-up areas reduces natural water absorption, increasing flood risks, particularly in low-lying informal settlements. Additionally, the high population density in unplanned settlements makes it difficult for authorities to implement effective climate adaptation measures, further exacerbating residents' vulnerability to climate hazards (Mukamana et al., 2023).

To address these challenges, city planners and policymakers need to implement sustainable urban development strategies. Strengthening urban planning regulations and enforcing Kigali's master plan will help control informal settlements and promote climate-resilient urban design. Additionally, investments in infrastructure, such as proper drainage systems and waste management, will be essential in mitigating the environmental risks associated with rapid urbanization (Alam et al., 2022). Furthermore, integrating green spaces and maintaining ecological zones will balance urban expansion with environmental sustainability, ensuring that urban growth does not come at the expense of climate resilience (Revi et al., 2020).

In conclusion, the LULC maps of Nyarugenge District reveal a significant shift in land use between 2010 and 2025, with increased urbanization in Gitega, Kigali, Muhima, and Kimisagara. While urban expansion has contributed to economic development, it has also introduced environmental and social challenges that require immediate attention. Sustainable land management policies, improved infrastructure, and strict urban planning

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regulations will be crucial in ensuring that urban growth enhances climate resilience and minimizes risks to vulnerable communities.

3.2. To assess community perceptions of climate risks in Nyarugenge District.

3.3.1 Perceived likelihood

The results presented in Table 2 highlight key insights into how urban residents perceive the likelihood of climate risks. The highest mean score (M = 4.60, SD = 0.596) was recorded for the statement that people in flood-prone areas perceive extreme weather events as more likely compared to those in safer locations.

This finding supports the availability heuristic theory (Tversky & Kahneman, 1974), which explains that individuals assess future risks based on past experiences. In flood-prone communities, recurrent exposure to extreme weather conditions reinforces the belief that such events will continue to occur (Wachinger et al., 2021).

Table 3.5: Survey data on perceived likelihood

	A		SA		N		D		SD		Mean	Std. Deviation
	F	%	F	%	F	%	F	%	F	%		
People in flood-prone areas may perceive the likelihood of extreme weather events as higher than those in safer locations.	112	28.4	254	64.3	22	5.6	0	0	0	0	4.60	.596
Education and awareness campaigns can help correct misperceptions about the likelihood of climate hazards.	107	27.1	249	63	22	5.6	10	2.5	0	0	4.53	.720
Scientific reports and weather forecasts play a role in shaping the public's perception of climate risks.	112	28.4	233	59	39	9.9	4	1	0	0	4.48	.717
The frequency of past climate events influences how likely people think future risks will occur.	105	26.6	241	61.0	22	5.6	20	5.1	0	0	4.46	.820
Valid N (listwise)												

Source: survey data2025

These perceptions often lead to heightened anxiety and increased calls for adaptive measures, but they may also result in fatalistic attitudes where residents feel powerless to change their circumstances.

Similarly, the statement that education and awareness campaigns can help correct misperceptions about climate risks received strong agreement (M = 4.53, SD = 0.720). This aligns with Protection Motivation Theory (Rogers, 1975), which suggests that risk perception and adaptive behavior improve when individuals are exposed to credible information. Research by Grothmann and Patt (2021) confirms that well-structured awareness initiatives significantly enhance public understanding of climate hazards, encouraging proactive measures. However, while information campaigns play a crucial

role, their effectiveness depends on accessibility and the level of trust in the sources delivering the message.

The role of scientific reports and weather forecasts in shaping climate risk perceptions was also evident, with a mean score of 4.48 (SD = 0.717). This supports the Social Amplification of Risk Framework (Kasperson et al., 1988), which posits that the media and experts shape public reactions to environmental threats. A study by Maibach et al. (2022) found that consistent exposure to scientific climate predictions improves risk awareness, particularly in urban settings where access to technology facilitates the dissemination of information. However, discrepancies between forecasts and actual events can sometimes lead to skepticism, reducing public trust in climate advisories.

Another key finding was that the frequency of past climate events significantly influences how people assess future risks (M = 4.46, SD = 0.820). This reflects the recency effect in cognitive bias theory (Slovic, 2020), where individuals give greater weight to recent extreme weather occurrences when forming risk perceptions. Research by Dessai and Sims (2023) supports this observation, noting that communities that have experienced recent floods, heatwaves, or landslides are more likely to anticipate similar events in the near future. While this heightened perception can drive urgent adaptation measures, it may also lead to exaggerated risk assessments that influence urban migration and land-use decisions.

Overall, these findings highlight the complex interplay between personal experience, education, media influence, and past events in shaping climate risk perceptions. The study reinforces the need for targeted awareness campaigns that combine scientific evidence with community engagement to ensure accurate understanding of climate hazards. Urban policymakers should leverage these insights to design localized adaptation strategies, particularly in high-risk areas such as Nyarugenge District. According to the IPCC (2021), integrating community-driven approaches with expert-led climate assessments can enhance resilience and foster sustainable urban development. Future research should explore how socio-economic factors, such as income and education, further shape climate risk perceptions in urban settings.

3.2.2 Perceived exposure

The findings presented in Table 3 provide important insights into how urban residents perceive their exposure to climate risks. The highest mean score (M = 4.53, SD = 0.762) corresponds to the perception that individuals living in informal settlements feel more exposed due to inadequate infrastructure. This aligns with the Vulnerability Theory (Wisner et al., 2004), which posits that socio-economic conditions and infrastructure deficiencies significantly heighten climate risk exposure. Informal settlements in urban areas, such as those in Nyarugenge District, often lack proper drainage systems, stable housing, and access to emergency response mechanisms, exacerbating residents' vulnerability to extreme weather events (Satterthwaite et al., 2021). As a result, residents in these areas may develop heightened risk perceptions, which influence their adaptive behavior and migration decisions.

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Table 3.6: Survey data on perceived exposure

	A		SA		N		D		SD		Mean	Std. Deviation
	F	%	F	%	F	%	F	%	F	%		
Individuals living in informal settlements may feel more exposed to climate risks due to inadequate infrastructure.	112	28.4	247	62.5	22	5.6	0	0	7	1.8	4.53	.762
Government initiatives, such as flood early warning systems, can reduce perceived exposure by enhancing preparedness.	79	20	241	61	68	17.2	0	0	0	0	4.45	.774
People with access to better housing and services often perceive themselves as less exposed to climate hazards.	113	28.6	227	57.5	41	10.4	0	0	7	1.8	4.43	.821
Urban residents who rely on climate-sensitive livelihoods, such as agriculture, may perceive greater exposure to risks.	84	21.3	211	53.4	56	14.2	30	7.6	7	1.8	4.19	1.061
Valid N (listwise)												

Source: survey data2025

The effectiveness of government initiatives, such as flood early warning systems, in reducing perceived exposure received a strong level of agreement (M = 4.45, SD = 0.774). This finding aligns with Risk Communication Theory (Fischhoff, 2020), which emphasizes the role of timely and reliable information in shaping public risk perceptions and preparedness. Research by Kreibich et al. (2021) suggests that early warning systems play a crucial role in improving community preparedness and reducing perceived exposure to climate hazards. However, the effectiveness of such initiatives depends on accessibility, trust in government institutions, and the ability of residents to act upon the warnings. In areas with high levels of informality and socio-economic constraints, warnings may not always translate into effective risk reduction strategies.

Another key finding is that people with access to better housing and services perceive themselves as less exposed to climate hazards (M = 4.43, SD = 0.821). This supports the Protective Action Decision Model (Lindell & Perry, 2012), which suggests that individuals with higher socio-economic stability and better living conditions feel more secure against environmental threats. Research by Adger et al. (2022) confirms that well-built housing, access to drainage systems, and the ability to relocate during extreme weather events contribute to lower perceived exposure. However, even in well-developed urban areas, climate risks such as heatwaves and water scarcity can still pose challenges, indicating that perceived safety does not always equate to actual risk reduction.

The lowest mean score in this table (M = 4.19, SD = 1.061) corresponds to the perception that urban residents engaged in climate-sensitive livelihoods, such as agriculture, feel more exposed to climate risks. This supports the Livelihood Vulnerability Framework (Turner et al., 2003), which argues that people whose income is directly dependent on environmental conditions are more susceptible to climate shocks. In urban areas like Nyarugenge, many

residents rely on informal agriculture, street vending, and weather-dependent businesses, which increases their exposure to extreme weather conditions, such as droughts and floods (Morton, 2021). The relatively higher standard deviation (SD = 1.061) suggests greater variability in responses, likely due to differences in adaptive capacity and resource access among individuals engaged in these livelihoods.

Overall, these findings highlight the intersection between socio-economic status, infrastructure availability, and risk perception in urban settings. Addressing these disparities requires a multi-faceted approach, combining improved urban planning, risk communication strategies, and targeted government interventions. As noted in the IPCC's Sixth Assessment Report (IPCC, 2021), reducing climate risk exposure in cities requires a combination of structural adaptation measures, such as resilient infrastructure, and non-structural strategies, such as education and community engagement. Future studies should explore how factors such as education level and trust in government policies influence perceptions of climate risk exposure in urban areas.

3.2.3. Adaptation strategies

The findings in this table highlight key factors influencing climate adaptation perceptions among urban residents. The highest mean score (M = 4.78, SD = 0.668) is associated with the perception that households with higher income levels are more likely to invest in adaptation measures, such as flood-resistant housing. This aligns with the Adaptation Finance Theory (Agrawala & Carraro, 2020), which posits that financial capacity plays a crucial role in determining an individual's ability to implement climate-resilient measures. Higher-income households often have better access to insurance, high-quality construction materials, and safer locations, thereby reducing their vulnerability to climate risks (Hallegatte et al., 2022). Conversely, low-income communities, particularly in informal settlements like those in Nyarugenge District, may lack the resources to invest in protective infrastructure, exacerbating their exposure to extreme weather events (Satterthwaite et al., 2021).

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Table 3.7: Survey data on Community-based adaptation strategies

	A		SA		N		D		SD		Mean	Std. Deviation
	F	%	F	%	F	%	F	%	F	%		
Households with higher income levels are more likely to invest in adaptation measures like flood-resistant housing.	43	10.9	332	84.1	2	0.5	5	1.3	6	1.5	4.78	.668
Government policies encouraging climate-resilient infrastructure can reduce vulnerability to climate risks.	42	10.6	332	84.1	3	0.8	4	1	7	1.8	4.77	.686
Community-based adaptation strategies, such as rainwater harvesting, can improve urban resilience.	79	20	287	72.7	17	4.3	2	0.5	3	0.8	4.66	.660
Access to climate risk information empowers individuals to adopt proactive adaptation strategies.	63	15.9	286	72.4	28	7.1	5	1.3	6	1.5	4.59	.806
Valid N (listwise)												

Source: survey data2025

The strong agreement regarding the role of government policies in reducing climate vulnerability (M = 4.77, SD = 0.686) supports Institutional Adaptation Theory (Biermann, 2021), which highlights the importance of regulatory frameworks in shaping climate resilience. Studies have shown that urban policies promoting resilient infrastructure such as flood drainage systems, green spaces, and sustainable urban planning can significantly mitigate climate risks (IPCC, 2021). However, the effectiveness of such policies often depends on enforcement mechanisms, public participation, and financial investments by both the government and private sector (Adger et al., 2022). In the context of Nyarugenge, infrastructure projects aimed at improving drainage systems and flood management could enhance long-term resilience, but equitable access to these interventions remains a challenge.

Community-based adaptation strategies, such as rainwater harvesting, were also perceived as an effective means of improving urban resilience (M = 4.66, SD = 0.660). This finding aligns with Community-Based Adaptation Theory (Reid & Schipper, 2020), which emphasizes local knowledge, grassroots initiatives, and collective action as critical elements in climate risk mitigation. Studies by Archer et al. (2021) indicate that localized adaptation strategies, such as community flood barriers, urban gardens, and water conservation programs, can enhance resilience while fostering social cohesion. However, the success of such initiatives largely depends on adequate funding, technical support, and community engagement. In rapidly urbanizing areas like Nyarugenge, integrating community-driven adaptation into formal policy frameworks could enhance long-term sustainability.

Finally, the perception that access to climate risk information empowers individuals to adopt proactive adaptation strategies (M = 4.59, SD = 0.806) supports Risk Perception and

Adaptive Capacity Theory (Grothmann & Patt, 2005). Research has shown that individuals who receive timely, accurate climate information are more likely to take precautionary measures, such as reinforcing their homes or altering livelihood strategies (Kreibich et al., 2021). The relatively higher standard deviation (SD = 0.806) suggests variation in responses, likely due to differences in education levels, access to communication channels, and trust in information sources. For example, while some residents may actively use meteorological reports and disaster alerts to inform their decisions, others may lack access to reliable climate information, leading to inconsistent adaptation behaviors (Fischhoff, 2020).

Overall, these findings emphasize the critical role of financial capacity, government policies, community initiatives, and information access in shaping urban climate adaptation. As highlighted in the IPCC Sixth Assessment Report (IPCC, 2021), a multi-level approach that integrates economic support, regulatory measures, and public engagement is necessary to enhance resilience in urban areas. Future research should explore how digital platforms and innovative financing mechanisms, such as climate insurance and microfinance for adaptation, can further improve adaptive capacity in vulnerable urban populations.

4.3.4. Experience with climate events

The findings in this table emphasize the role of personal experience in shaping perceptions and responses to climate risks. The highest mean score (M = 4.65, SD = 0.784) corresponds to the perception that individuals who have previously experienced floods or heatwaves are more likely to take climate risks seriously. This finding aligns with Protection Motivation Theory (PMT) (Rogers, 1975), which suggests that individuals assess threats based on their past experiences and respond by adopting protective behaviors (Bubeck et al., 2021). Studies indicate that direct exposure to climate-related disasters often increases risk awareness and preparedness, as people who have suffered losses due to extreme weather events become more proactive in seeking adaptation measures (van Valkengoed & Steg, 2019).

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Table 3.8: Survey data on experience with climate events

	A		SA		N		D		SD		Mean	Std. Deviation
	F	%	F	%	F	%	F	%	F	%		
People who have previously experienced floods or heatwaves are more likely to take climate risks seriously.	69	12.5	298	75.4	3	0.8	12	3	6	1.5	4.65	.784
Lack of past experience with extreme weather can lead to complacency in climate risk preparedness.	62	15.7	265	67.1	36	9.1	18	4.6	7	1.8	4.44	.964
Direct experience with climate hazards can motivate individuals to adopt preventive measures.	63	15.9	244	61.8	44	11.1	25	6.3	12	3	4.29	1.093
Communities with frequent climate-related disasters develop local coping mechanisms over time.	73	18.5	244	61.8	2	0.5	57	14.4	12	3	4.24	1.203

Source: survey data2025

In urban settings such as Nyarugenge District, residents in flood-prone areas may be more inclined to reinforce their homes, participate in early warning systems, or support local climate initiatives compared to those with no prior exposure.

Conversely, the statement that a lack of past experience with extreme weather can lead to complacency in climate risk preparedness (M = 4.44, SD = 0.964) highlights a psychological barrier to climate adaptation. According to Availability Heuristic Theory (Tversky & Kahneman, 1973), individuals tend to assess risks based on recent or personal experiences rather than statistical data (Weber, 2020). This may explain why some residents in urban areas with fewer climate-related disasters underestimate the likelihood of future risks and fail to take necessary precautions (Whitmarsh, 2021). The relatively high standard deviation suggests that perceptions vary significantly among respondents, possibly due to differences in education, media exposure, or trust in scientific reports. Public awareness campaigns and community engagement initiatives can help address this gap by reinforcing climate risk education and ensuring that even those who have not personally experienced disasters remain vigilant.

The perception that direct experience with climate hazards can motivate individuals to adopt preventive measures (M = 4.29, SD = 1.093) further supports the role of lived experiences in driving behavioural change. According to Experiential Learning Theory (Kolb, 1984), individuals learn and adapt best through direct encounters with real-world challenges. Research by Kreibich et al. (2021) confirms that people who have suffered from past disasters, such as flooding, tend to invest in precautionary actions such as securing their homes, adopting emergency preparedness plans, or relocating to safer areas. However, the relatively high standard deviation (SD = 1.093) suggests variability in responses, indicating that while some individuals take proactive measures after experiencing climate events, others may lack the resources or awareness to do so. This underscores the need for

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government support, financial assistance, and accessible climate adaptation programs tailored to vulnerable populations in cities like Nyarugenge.

Finally, the perception that communities with frequent climate-related disasters develop local coping mechanisms over time (M = 4.24, SD = 1.203) is consistent with Community Resilience Theory (Norris et al., 2008). Studies by Satterthwaite et al. (2021) indicate that repeated exposure to climate shocks can lead to the development of adaptive practices, such as early warning systems, community flood defenses, and informal support networks. However, the relatively high standard deviation (SD = 1.203) suggests differing levels of resilience among communities, possibly due to variations in social cohesion, economic resources, and institutional support. In Nyarugenge, neighborhoods that frequently experience floods or heatwaves may have stronger coping mechanisms compared to less affected areas, reinforcing the importance of integrating local knowledge and participatory planning into broader climate adaptation policies.

Overall, these findings highlight the importance of direct experience in shaping climate risk perceptions and behaviors. As supported by research from the IPCC Sixth Assessment Report (IPCC, 2021), integrating experiential learning, risk communication, and localized adaptation strategies into climate policies can enhance urban resilience. Future studies should explore how digital platforms, social media, and virtual simulations can be leveraged to improve climate risk perception among populations with limited past exposure to extreme weather events.

Table 3.9: disaster effect situation in nyarugenge district

District	N of Incidents	Deaths	Injured	Houses destroyed	Houses damaged	Damages in crops (Ha)	Forest (Ha)	Road sections	bridges	Administrative offices	Transition line	Factory
Nyarugenge District	69	6	14	3	88	1.5	3	3	1	3	1	1

Source: MINEMA, 2024

Nyarugenge District in Kigali, Rwanda, has been increasingly vulnerable to climate-induced events, particularly floods and landslides, which have led to significant human and infrastructural losses. The data found from MINEMA underscores the severity of these impacts, highlighting the urgent need for effective mitigation strategies(Izere et al., 2024).

The Nyabugogo Valley within Nyarugenge District has been notably affected by periodic flooding. The root causes have been identified as environmentally damaging activities in the surrounding catchment areas. The correlation between increased rainfall and flood risks in Nyarugenge has been substantiated by research. A study analyzing rainfall and flood risk variations from 2016 to 2020 demonstrated that higher precipitation levels directly influenced flood risk factors, including infrastructure damage, crop loss, injuries, and fatalities. The year 2018, in particular, witnessed significant losses, emphasizing the need for accurate rain forecasting and proactive flood risk reduction measures.

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Personal interpretations further illuminate the human impact of these climate events. For instance, In MINEMA report 2020, intensive rainfall caused the Mpazi water channel in Nyarugenge to overflow, leading to the destruction of homes and the displacement of numerous families. This incident underscores the compounded challenges of unplanned urbanization and climate change, highlighting the necessity for comprehensive urban planning and community engagement in developing solutions.

These experiences align with broader regional patterns. The 2020 East Africa floods resulted in 97 fatalities in Rwanda, with heavy rains triggering floods and landslides across various districts, including Nyarugenge district. This event highlights the widespread nature of climate-induced disasters in the region and the imperative for coordinated disaster preparedness and response strategies.

The recurring climate events in Nyarugenge District reflect a critical intersection of environmental challenges and socio-economic vulnerabilities. Addressing these issues necessitates a multifaceted approach, encompassing environmental conservation, infrastructural resilience, accurate weather forecasting, and active community participation. Such strategies are vital to mitigate the adverse impacts of climate change and safeguard the well-being of the district's residents.

3.4. Evaluating the social economic factors

3.4.1 Income level

The findings in this table highlight the strong correlation between economic status and climate risk exposure, emphasizing how income levels influence vulnerability and adaptation capacity. The highest mean score (M = 4.79, SD = 0.652) corresponds to the perception that low-income households often settle in high-risk areas due to affordability constraints. This aligns with the Structural Constraints Theory (Moser & Felton, 2007), which suggests that economic limitations force marginalized communities to inhabit areas prone to flooding, landslides, or extreme heat.

Table 3.10: Survey data on Income level

	A		SA		N		D		SD		Mean	Std. Deviation
	F	%	F	%	F	%	F	%	F	%		
Low-income households often settle in high-risk areas due to affordability constraints.	42	10.6	334	84.6	2	0.5	4	1	6	1.5	4.79	.652
Government subsidies and financial aid can help lower-income groups implement climate adaptation measures.	254	64.3	122	30.9	2	0.5	4	1	6	1.5	4.24	.665
Higher-income individuals can afford climate-resilient housing and insurance, reducing their vulnerability.	43	10.9	220	55.7	114	28.9	4	1	7	1.8	4.20	1.014
Economic stability enables individuals to invest in adaptation strategies such as home improvements.	237	60	81	20.5	56	14.2	4	1	10	2.5	3.97	.792

Source: survey data2025

Studies by Dodman et al. (2021) indicate that urbanization pressures and land scarcity in cities such as Kigali push lower-income populations into informal settlements lacking adequate infrastructure, thereby increasing their susceptibility to climate hazards. The relatively low standard deviation (SD = 0.652) suggests strong agreement among respondents, reinforcing the notion that financial constraints are a key determinant of climate risk exposure in urban areas.

The perception that government subsidies and financial aid can help lower-income groups implement climate adaptation measures (M = 4.24, SD = 0.665) underscores the role of public policy in enhancing resilience. According to the Public Goods Theory (Samuelson, 1954), state interventions, such as subsidized housing, climate-proof infrastructure, and direct financial assistance, can mitigate socio-economic disparities in climate adaptation. Research by Fankhauser & McDermott (2022) shows that well-designed subsidy programs, including targeted financial support for climate adaptation in vulnerable areas, have been effective in reducing risk exposure in cities across Africa. However, the moderate standard deviation (SD = 0.665) suggests some variation in perceptions, likely due to differing levels of awareness or access to government programs among respondents. This finding highlights the need for improved communication and equitable distribution of climate adaptation resources.

The perception that higher-income individuals can afford climate-resilient housing and insurance, reducing their vulnerability (M = 4.20, SD = 1.014), reflects the concept of Adaptive Capacity Theory (Smit & Wandel, 2006). This theory suggests that wealthier individuals have greater financial resources to invest in protective measures such as flood-resistant homes, air conditioning, and comprehensive insurance policies (Hallegatte et al., 2020). However, the relatively high standard deviation (SD = 1.014) indicates substantial variability in responses, suggesting that not all high-income individuals necessarily prioritize climate adaptation investments. This aligns with findings by Thomas et al. (2021), which suggest that personal risk perception and awareness, rather than income alone, play a critical role in adaptation decisions.

The lowest mean score (M = 3.97, SD = 0.792) corresponds to the perception that economic stability enables individuals to invest in adaptation strategies such as home improvements. While this finding supports the notion that financial security facilitates long-term climate adaptation investments, the lower mean score suggests that other factors such as awareness, policy incentives, and cultural attitudes also influence decision-making. According to Behavioral Economics Theory (Thaler & Sunstein, 2008), even financially capable individuals may delay adaptation measures due to cognitive biases, lack of urgency, or competing financial priorities. Research by Sovacool et al. (2021) highlights the importance of behavioral interventions, such as nudging strategies and climate risk education, in encouraging proactive adaptation measures across all income levels.

Overall, these findings emphasize the critical role of economic status in climate vulnerability and adaptation. As the IPCC Sixth Assessment Report (IPCC, 2021) suggests, integrating financial support mechanisms, policy incentives, and behavioral change strategies can enhance climate resilience across diverse socio-economic groups. Future studies should explore the effectiveness of financial literacy programs and climate insurance models tailored for low- and middle-income populations to bridge adaptation gaps.

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3.4.2. Education

The results in this table highlight the role of education in shaping climate resilience, risk perception, and adaptive decision-making. The highest mean score (M = 4.41, SD = 0.825) corresponds to the perception that education enhances decision-making regarding land use and resource management for climate resilience.

Table 3.11: Survey data on Education

	A		SA		N		D		SD		Mean	Std. Deviation
	F	%	F	%	F	%	F	%	F	%		
Education can enhance decision-making regarding land use and resource management for climate resilience.	130	32.9	217	54.9	31	7.8	2	0.5	8	2	4.41	.825
School-based climate education programs can shape long-term risk perception and preparedness.	255	64.6	81	20.5	47	11.9	2	0.5	3	0.8	4.05	.647
Educated individuals are more likely to trust scientific information about climate change.	258	65.3	56	14.2	58	14.7	13	3.3	3	0.8	3.90	.700
Higher levels of education correlate with better awareness of climate risks and adaptation options.	169	42.8	81	20.5	87	22	37	9.4	14	3.5	3.69	1.021

Source: survey data2025

This finding aligns with the Human Capital Theory (Becker, 1964), which suggests that education equips individuals with the knowledge and skills necessary to make informed choices, including sustainable land use and resource conservation strategies. Studies by Pahl-Wostl et al. (2020) emphasize that education fosters a proactive approach to climate adaptation, as individuals with formal training in environmental sciences or related fields are more likely to implement effective resilience strategies. The moderate standard deviation (SD = 0.825) suggests some variation in responses, likely influenced by differences in educational backgrounds and access to climate-related learning resources.

The perception that school-based climate education programs can shape long-term risk perception and preparedness (M = 4.05, SD = 0.647) underscores the importance of integrating climate change topics into formal curricula. According to Social Learning Theory (Bandura, 1977), early exposure to environmental education in schools can shape attitudes and behaviors toward climate adaptation from a young age. Research by Stevenson et al. (2021) supports this claim, indicating that climate literacy programs in schools significantly improve students' understanding of climate risks and their ability to engage in mitigation and adaptation practices. The relatively low standard deviation (SD = 0.647) suggests a strong consensus among respondents, reinforcing the belief that school-

based interventions play a crucial role in long-term climate resilience.

The perception that educated individuals are more likely to trust scientific information about climate change (M = 3.90, SD = 0.700) reflects findings from Cognitive Bias and Information Processing Theories (Kahneman & Tversky, 1979). These theories suggest that education reduces susceptibility to misinformation and enhances the ability to critically evaluate scientific data. According to van der Linden et al. (2020), individuals with higher levels of formal education exhibit greater trust in scientific research on climate change and are more likely to support evidence-based policies. The moderate standard deviation (SD = 0.700) indicates general agreement among respondents, although variations may exist due to factors such as political ideology or exposure to misinformation.

The lowest mean score (M = 3.69, SD = 1.021) corresponds to the perception that higher levels of education correlate with better awareness of climate risks and adaptation options. While this finding supports the Knowledge-Attitude-Behavior Model (Ajzen, 1991), which suggests that increased knowledge leads to behavioral change, the relatively high standard deviation (SD = 1.021) indicates significant variability in responses. This may be attributed to the fact that education alone does not automatically translate into climate action; socio-economic factors, cultural beliefs, and access to climate-related information also play crucial roles (Whitmarsh et al., 2021).

Overall, these findings emphasize the role of education in fostering climate resilience but also highlight the need for targeted climate literacy initiatives. As recommended by the IPCC Sixth Assessment Report (IPCC, 2021), integrating climate education into school curricula, promoting community-based learning, and improving public access to scientific information can enhance societal adaptation to climate risks. Future studies should explore the effectiveness of different climate education models in influencing behavioral change across diverse populations.

3.4.3. Access to basic service

The findings in this table emphasize the role of infrastructure and services in enhancing community resilience to climate-related risks. The highest mean score (M = 4.30, SD = 0.926) corresponds to the perception that access to early warning systems and emergency response services improves community resilience. This aligns with the Disaster Risk Reduction (DRR) Framework (UNDRR, 2019), which emphasizes the importance of proactive preparedness and rapid response in reducing disaster impacts. Studies by Cutter et al. (2020) suggest that communities with well-developed early warning systems experience lower mortality and economic losses during extreme weather events. The moderate standard deviation (SD = 0.926) suggests some variation in responses, possibly influenced by differences in respondents' access to such services.

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Table 3.12: Access to basic service

	A		SA		N		D		SD		Mean	Std. Deviation
	F	%	F	%	F	%	F	%	F	%		
Access to early warning systems and emergency response services improves community resilience.	130	32.9	203	51.4	32	8.1	15	3.8	8	2	4.30	.926
Limited access to services increases reliance on informal coping mechanisms, which may be less effective.	123	31.1	205	51.9	34	8.6	16	41	10	2.5	4.28	.968
Reliable access to water, sanitation, and healthcare reduces vulnerability to climate-related health risks.	128	32.4	200	50.6	37	9.4	15	3.8	8	2	4.28	.935
Areas with better drainage and waste management systems experience lower flood impacts.	121	30.6	203	51.4	37	9.4	19	4.8	8	2	4.27	.965

Source: survey data2025

The perception that limited access to services increases reliance on informal coping mechanisms, which may be less effective (M = 4.28, SD = 0.968), highlights the vulnerability of underserved communities. According to Social Vulnerability Theory (Adger, 2006), marginalized populations often depend on traditional or community-based coping mechanisms, which may lack the efficiency of formal adaptation measures. Research by Moser and Ekstrom (2021) supports this, showing that informal strategies, such as borrowing resources from neighbors or temporary relocation, provide short-term relief but do not address long-term climate resilience. The relatively high standard deviation (SD = 0.968) suggests diverse experiences, possibly influenced by socio-economic disparities and varying degrees of service availability.

The same mean score (M = 4.28, SD = 0.935) is observed for the statement that reliable access to water, sanitation, and healthcare reduces vulnerability to climate-related health risks. This aligns with findings from the Sustainable Development Goals (SDG 6 & 3), which emphasize the role of clean water, sanitation, and healthcare in reducing climate-sensitive diseases such as cholera and malaria (WHO, 2021). Research by Watts et al. (2020) indicates that climate change exacerbates public health risks, particularly in communities with inadequate healthcare infrastructure. The moderate standard deviation (SD = 0.935) suggests relative agreement among respondents, though variations may exist due to differing levels of access to these services.

The lowest mean score (M = 4.27, SD = 0.965) is associated with the perception that areas with better drainage and waste management systems experience lower flood impacts. This finding aligns with Urban Resilience Theory (Ahern, 2011), which highlights the importance of infrastructure in reducing disaster risks. Studies by Zhou et al. (2022)

demonstrate that effective drainage systems significantly lower flood risks in urban areas, preventing property damage and public health crises. The moderate standard deviation (SD = 0.965) indicates some variability in responses, likely influenced by differences in urban planning and investment in drainage infrastructure across communities.

Overall, these findings reinforce the critical role of access to services and infrastructure in building climate resilience. As recommended by The Sendai Framework for Disaster Risk Reduction (2015-2030), governments should prioritize investments in climate-resilient infrastructure, early warning systems, and public health services to mitigate climate risks effectively. Future research should explore the effectiveness of specific interventions, such as decentralized early warning systems and community-led waste management programs, in enhancing adaptive capacity.

3.5. The relationship between urbanization and community perception of climate risks in Nyarugenge District.

The study findings reveal a complex relationship between urbanization, vulnerability, and community perceptions of climate risks in Nyarugenge District. Rapid urbanization has driven population growth and the expansion of informal settlements, increasing exposure to flooding and heat stress. Residents in flood-prone areas perceive extreme weather events as highly likely (M = 4.60, SD = 0.596), showing that past experiences strongly shape risk assessments. Education and awareness campaigns significantly influence perceptions (M = 4.53, SD = 0.720), with educated individuals more likely to trust scientific information (M = 3.90, SD = 0.700) and engage in proactive adaptation. Economic status also affects resilience—low-income households often reside in high-risk areas (M = 4.79, SD = 0.652) with limited adaptation options, while wealthier residents invest in flood-resistant housing (M = 4.78, SD = 0.668). Moreover, access to early warning systems (M = 4.30, SD = 0.926) enhances preparedness, whereas lack of services increases reliance on informal coping mechanisms (M = 4.28, SD = 0.968). Overall, the findings underscore the need for targeted interventions that improve infrastructure, expand climate education, and enhance adaptive capacity in vulnerable communities to strengthen Nyarugenge's overall climate resilience.

3. Conclusion

In conclusion, the findings of this study highlight the complex interplay between urbanization patterns and community perceptions of climate risks in Nyarugenge District. Key factors such as occupation, education level, length of residence, and type of housing significantly influence climate resilience, with low-income households often residing in high-risk areas due to affordability constraints. Education emerges as a critical component, enhancing individuals' capacity to understand and respond to climate information, while access to essential services like early warning systems is vital for effective risk management. Moreover, the rapid urbanization and resulting informal settlements exacerbate vulnerabilities, necessitating targeted interventions that address infrastructure deficits and promote community engagement in climate adaptation strategies. Overall, a collaborative approach that integrates financial support, education, and improved services is essential for fostering resilience against climate challenges in Nyarugenge District.

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