The Impacts of Land Use Change on Ecosystem Services in Rwanda: A Case of Bugesera District

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The study titled "The Impacts of Land Use Change on Ecosystem Services in Rwanda: A Case of Bugesera District" investigates how agricultural expansion and urbanisation affect ecosystem services such as water quality, biodiversity, soil fertility, and carbon sequestration in Bugesera District. The research addresses concerns over environmental degradation driven by rapid land-use changes, which challenge sustainable development goals in the region. Using a mixed-methods approach, the study analyses satellite imagery and land cover maps from 2004 to 2024, alongside survey data from 99 local government employees. Statistical tools, including linear regression via SPSS, were used to assess the impact of land use changes on ecosystem services. The analysis revealed major shifts: agricultural land decreased by 51%, while built-up areas surged by 5,800%, indicating rapid urban growth fueled by population increase and infrastructure expansion. The findings showed a significant negative correlation between agricultural expansion and ecosystem services, with a decline of 0.061 in services per unit of agricultural growth. Urbanization had a mildly positive, though statistically insignificant, effect (coefficient of 0.077). Population and settlement growth, however, had a statistically significant positive effect ($p = 0.038 < 0.05$). Despite these correlations, the model had a modest explanatory power ($R^2 = 0.154$), suggesting additional factors influence ecosystem degradation. Environmental impacts include a 70% decline in water quality due to runoff and urban waste, a 32% drop in biodiversity from habitat loss, and a 19% reduction in carbon sequestration linked to deforestation and wetland conversion. The study concludes that land use changes are driving environmental decline in Bugesera and recommends sustainable land use policies, conservation practices, and improved integration of ecosystem services into planning. Future research should explore broader national impacts and the role of climate change.

Keywords: Land Use Change; Ecosystem Services; Agricultural Expansion; Urbanization.

Introduction

Land use change is a significant environmental issue with global implications for ecosystem services, influencing biodiversity, climate regulation, and natural resources. Over recent decades, rapid urbanization, agricultural expansion, and industrialization have dramatically altered landscapes in both developed and developing countries, with consequences for ecosystem functions (Foley, 2020). In regions such as North America, Asia, and Europe, land use changes have led to habitat fragmentation, biodiversity loss, and the depletion of vital ecosystem services like water filtration, soil fertility, and carbon sequestration (Tilman, 2021; McDonald, 2024). These shifts are primarily driven by population growth, economic development, and intensifying agricultural practices.

In North America, agricultural expansion, particularly in the U.S. and Canada, has converted forests and wetlands into farmland, reducing essential services such as flood regulation and wildlife habitat (Tilman, 2021).

Similarly, urbanisation has increased impervious surfaces, exacerbating flooding, biodiversity loss, and greenhouse gas emissions (McDonald, 2024). Efforts to mitigate these effects include policies like land-use zoning and conservation programs to encourage sustainable development.

Asia has seen rapid urbanization and agricultural intensification, particularly in China, India, and Indonesia. These changes have caused soil erosion, water pollution, and the loss of ecosystem services crucial for food production (Liu, 2023). Southeast Asia faces further challenges, as large-scale agricultural operations, such as oil palm plantations, have destroyed critical habitats and threatened biodiversity (Gaveau, 2024). In Europe, while urbanization has slowed in many Western countries, Eastern and Southern Europe continue to experience land-use pressures from urban sprawl and industrialization, prompting policies aimed at sustainable land management (McDonald, 2024).

Africa, particularly Sub-Saharan Africa, faces significant land use change challenges, driven by population growth, urbanization, and agricultural expansion. In countries like Nigeria, Kenya, and Ethiopia, agricultural intensification and urban sprawl have led to reduced agricultural productivity, soil degradation, and declining water quality (Haen, 2021). The region struggles with unsustainable land management practices, which undermine ecosystem services, making it essential to integrate ecosystem conservation into development policies.

East Africa, including Rwanda, faces unique challenges regarding land use change. Rapid population growth and urbanization have intensified pressure on land and resources. In Kenya, for example, agricultural expansion has been linked to deforestation and soil erosion (Ndiritu, 2021). Rwanda, a densely populated, landlocked country, is undergoing significant changes in land use, particularly in rural areas, where forests and wetlands are converted into agricultural land. These changes threaten biodiversity, disrupt water retention, and diminish carbon storage (Gaveau, 2024). Urbanization, especially in satellite cities like Bugesera, adds to these pressures as sprawl encroaches on previously natural landscapes.

Bugesera District, located in Rwanda's Eastern Province, exemplifies the challenges of balancing development with environmental conservation. The district has seen increasing agricultural activity and urbanization, as the Rwandan government seeks to promote economic growth through agricultural intensification and the creation of urban hubs like Bugesera District. This project aims to enhance infrastructure, create jobs, and attract investment (NISR, 2021). However, the rapid development has raised concerns about the negative environmental impacts of land use change, especially regarding ecosystem services.

The conversion of wetlands and forests into farmland in Bugesera threatens local biodiversity, disrupts water cycles, and exacerbates water scarcity, particularly concerning given the semi-arid climate of the region. The use of chemical fertilizers and pesticides in agriculture further degrades soil quality, water resources, and community health. Meanwhile, urbanization increases demand for land, leading to infrastructure development that fragments natural habitats and contributes to environmental degradation (McDonald, 2024).

The case of Bugesera underscores the importance of integrated land use planning, where ecosystem services are considered alongside development needs. The challenge lies in balancing agricultural expansion and urbanization with the conservation of ecosystem services such as water retention, soil fertility, and carbon sequestration. Effective land management policies are essential to mitigate the adverse impacts of land use change, ensuring the long-term sustainability of Bugesera's environment and the well-being of its population.

This study will focus on assessing the impacts of land use change on ecosystem services in Bugesera, exploring the patterns and drivers of land use changes, particularly agricultural expansion and urbanization, and their effects on ecosystem characteristics. The study will examine the relationship between land use change and ecosystem services, contributing to the broader understanding of how such transformations impact environmental sustainability in Rwanda. Through this analysis, the study aims to inform policies that support sustainable land use practices and preserve vital ecosystem services for the region's future development.

Land use change driven primarily by agricultural expansion and urbanization has become a major driver of environmental transformation and socioeconomic change in Rwanda. In pursuit of economic growth and poverty reduction, the Rwandan government has prioritized rapid urban development and intensified agriculture, particularly in areas like Bugesera District (Ndayambaje, 2021). Bugesera, identified as a strategic

growth zone, is experiencing significant infrastructure development and land conversion to support the needs of a growing population (Ministry of Infrastructure, 2020).

While these land use changes aim to improve food security and urban living standards, they simultaneously exert mounting pressure on vital ecosystem services such as water regulation, soil fertility, carbon storage, and biodiversity. These services are essential for the health of natural systems and the well-being of communities that depend on them (Sharma, 2021). In Bugesera, where semi-arid conditions already challenge environmental resilience, the uncoordinated transformation of land poses a heightened risk to ecosystem sustainability.
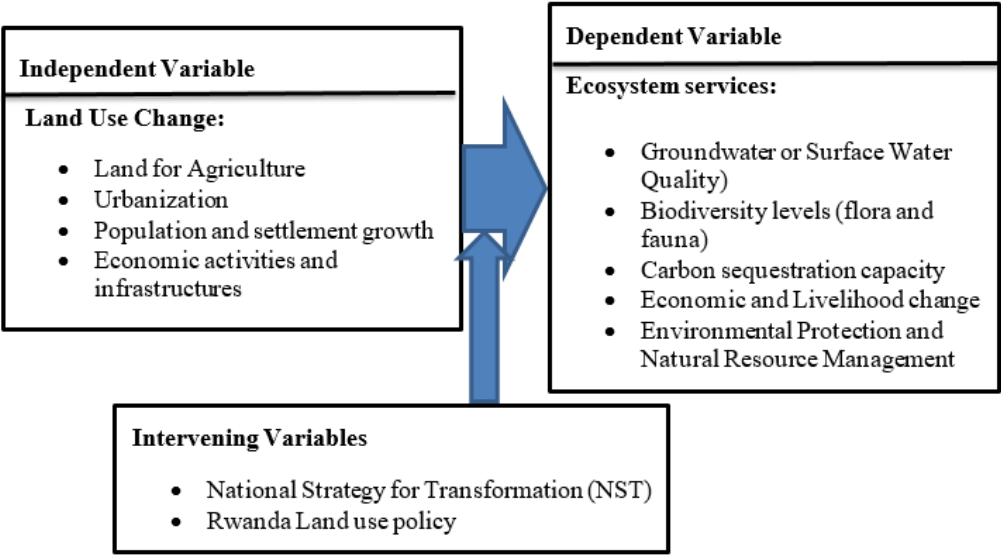
The expansion of agricultural land often results in deforestation, soil erosion, and habitat loss, while urbanization fragments natural landscapes, pollutes water resources, and contributes to the decline of local climate-regulating functions (Zhang et al., 2018; McDonald, 2022). Yet, despite these clear pressures, there is a limited understanding of how specific patterns and drivers of land use change are altering the quantity and quality of ecosystem services in Bugesera District. Moreover, the linkages between land use dynamics and ecosystem functionality remain under-explored in this context, creating a gap in knowledge that hinders evidence-based policy and planning.

This study aims to fill that gap by (i) analyzing the patterns and drivers of land use change in Bugesera District, (ii) assessing the current state and characteristics of ecosystem services, and (iii) examining the relationship between land use change and ecosystem service provision. The findings will offer critical insights for planners and policymakers, supporting the development of land management strategies that safeguard ecosystem integrity while accommodating economic development. By doing so, the research will contribute to Rwanda's broader goals of achieving sustainable and inclusive development (Republic of Rwanda, 2024).

Research Objectives

The main objective of this study is to assess the impacts of land use change on ecosystem services in Rwanda: a case of Bugesera District. This broad objective is further examined under the following specific objectives: (i) to analyze the patterns and drivers of land use change in Bugesera District, (ii) to assess the ecosystem services characteristics in Bugesera District and (iii) to examine the relationship between land use change and ecosystem services in Bugesera District.

Conceptual framework of the study

Figure 1: Conceptual framework

The expansion of agricultural land and urban areas in Bugesera has a direct impact on the environment, particularly the quality of ecosystem services that local communities rely on. As more land is converted for farming, natural habitats are lost, which can lead to soil degradation and increased erosion. This affects soil

fertility, making it harder to grow crops and ultimately impacting food security. Similarly, urban growth leads to the loss of green spaces and increases pollution, which can degrade water quality by introducing chemicals from farming or runoff from urban areas.

These changes can reduce the ability of the land to provide clean water, fertile soils, and biodiversity, all of which are essential for the well-being of both the environment and the people living in Bugesera. As land use changes in the area, local ecosystems suffer, leading to broader consequences for sustainable development. The loss of forests and natural vegetation diminishes the land's ability to absorb carbon and regulate the climate. Soil erosion and decreased fertility reduce agricultural productivity, making it harder for farmers to sustain their livelihoods. Water sources become polluted, affecting both drinking water quality and agricultural irrigation. These environmental changes can lead to economic hardships for communities, especially those reliant on agriculture. Moreover, as natural resources dwindle, the region may struggle to maintain long-term economic growth and social stability, as the balance between development and environmental protection becomes increasingly difficult to manage.

However, national strategies and policies play an important role in guiding how land is used and can help mitigate some of these negative effects. Government initiatives that promote sustainable land management and urban planning can help reduce the environmental impact of agricultural expansion and urban growth. By following clear guidelines for land use, it is possible to prevent excessive damage to ecosystems while still achieving the economic and social goals of the region. These policies ensure that development projects are aligned with long-term sustainability, protecting natural resources while supporting economic growth and improving the quality of life for local communities.

Research Method

This study employs a descriptive research design to assess the impacts of land use change on ecosystem services in Bugesera District, Rwanda. Utilizing both qualitative and quantitative approaches, the study gathers primary data via structured questionnaires and interviews from a census of 99 stakeholders involved in land management across district, sector, and cell levels. Secondary data sources, including satellite imagery and government reports, complement the primary data, enabling the analysis of land cover transitions over two decades. Statistical techniques such as Pearson correlation and regression analysis are used to examine relationships between land use changes (e.g., agriculture, urbanization) and ecosystem service variables like biodiversity, water quality, and soil fertility. Tools such as SPSS and GIS software were employed for data processing, with reliability and validity confirmed through high Cronbach's alpha values and a 91.4% content validity index.

The study focuses on Bugesera District, an area experiencing rapid demographic and economic transformation, influenced by urban expansion and proximity to Kigali. While development initiatives aim to boost the economy, they have also intensified land use changes that threaten ecosystem services. The research emphasizes the critical need for sustainable land management practices, supported by findings from spatial analysis using GIS and remote sensing. Limitations include the restricted sample size and geographic scope, which may limit generalizability, and challenges in establishing causality due to the long-term nature of land use impacts. Ethical research practices were upheld through informed consent, confidentiality, and institutional approvals, ensuring the integrity and reliability of the study process and outcomes.

Results

The demographic and professional background of respondents in Bugesera District reflects a knowledgeable and relatively experienced population. The study involved 99 individuals, most of whom were mid-career professionals with significant involvement in land use management and socio-economic development. Men made up 58.6% of respondents, while women accounted for 41.4%, showing a near-balanced gender representation. Most respondents were aged between 30 and 45, and 74.8% were married, suggesting a mature and stable workforce. Additionally, 92.9% reported no vulnerability status, further indicating socio-economic stability. Their professional experience ranged from 3 to over 12 years, and educationally, most held university degrees (A0 and A1), with 8.1% possessing a Master's degree. This combination of experience and education

suggests that the respondents are well-positioned to provide informed perspectives on land use and ecosystem dynamics in the district.

Land use change in Bugesera District is primarily driven by agricultural expansion, urbanization, and population growth, each contributing to the transformation of natural landscapes. The majority of respondents strongly agreed that agricultural land has expanded in recent years, often at the expense of forests, wetlands, and biodiversity. Urbanization was also seen as a major driver, with respondents noting rapid growth in built-up areas, infrastructure, and the conversion of farmland into residential and industrial zones. Additionally, population growth has increased the demand for housing, resulting in the spread of informal and formal settlements into previously undeveloped areas. Census data from 2022 confirms these trends, with Bugesera's urban population growing to 40.1%, particularly in sectors like Rilima and Nyamata. These changes reflect broader patterns of rural-to-urban transition, posing challenges for sustainable land management and the preservation of ecosystem services in the district.

In Bugesera District, household settlement patterns are dominated by Umudugudu (planned rural settlements), accounting for 85.6% of all households, making it the most prevalent settlement type across both urban (79.3%) and rural (89.8%) areas. The district also includes smaller proportions of dispersed/isolated housing (5.4%) and spontaneous/squatter housing (4.2%), which are more common in specific sectors like Juru and Ntarama. Sector-level data reveal substantial variation, with places like Gashora and Nyarugenge showing nearly universal adoption of planned settlements, while Juru has the lowest proportion of Umudugudu and the highest levels of informal and dispersed housing. These varying settlement patterns have direct implications for land use, contributing to urban sprawl and ecosystem degradation as housing expands into natural and agricultural areas.
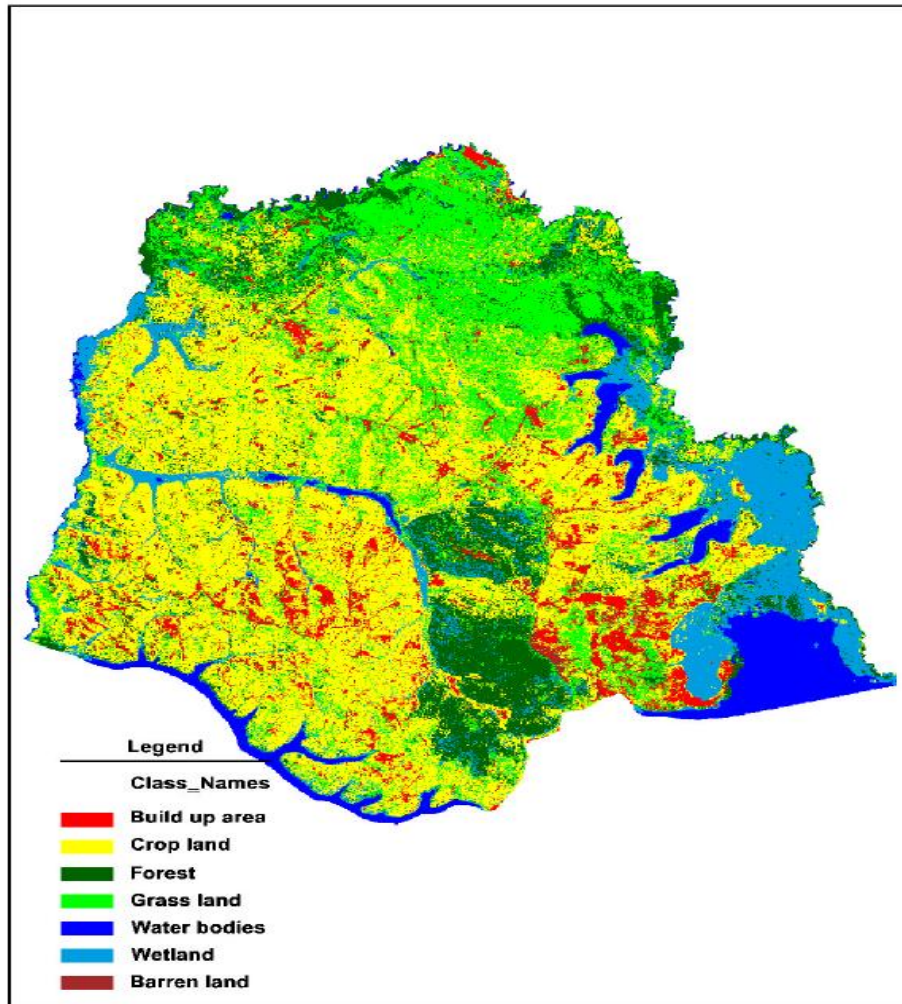
Table 1: Bugesera District Land use change from 2004 to 2024 (20 years back)

Land Use Activities	2004 Area in km²	Share in %	Change 2004 to 2014 in km²	2014 Area in km²	Share in %	Change 2014 to 2024 in km²	2024 Area in km²	Share in %	Change 2004 to 2024 in km²
Built up area	2.6	0.205	12.0	14.6	1.136	139.9	154.5	11.994	151.84
Cropland	814.2	63.214	222.9	1,037.1	80.523	-531.2	505.9	39.28	-308.27
Forest	99.4	7.718	-58.9	40.5	3.145	298.4	338.9	26.309	239.45
Grassland	315.0	24.457	-173.5	141.5	10.989	51.4	193.0	14.982	-122.04
Water bodies	4.5	0.352	-1.0	3.5	0.273	8.1	11.6	0.901	7.07
Wetland	52.2	4.055	-1.6	50.7	3.934	33.5	84.2	6.534	31.93
Total	**1,288.0**	**100.0**	**N/A**	**1,288.0**	**100.0**	**N/A**	**1,288.0**	**100.0**	**N/A**

Source: Primary Data, 2025

The study of land use change and its impacts on ecosystem services is crucial for understanding the dynamics of environmental sustainability and development. This analysis focuses on Bugesera District in Rwanda, examining the patterns and drivers of land use change over a 20-year period from 2004 to 2024. The study also assesses the characteristics of ecosystem services in the district and explores the relationship between land use change and ecosystem services. The data presented in the table and figures provide a comprehensive overview of these changes, offering insights into the implications for environmental management and policy-making.

The table 1 illustrates significant changes in land use activities in Bugesera District over the 20-year period. The most notable change is the dramatic increase in built-up areas, which expanded from 2.6 km² in 2004 to 154.5 km² in 2024. This represents a total increase of 151.84 km², indicating rapid urbanization and infrastructure development. The share of built-up areas in the total land area increased from 0.205% to 11.994%, reflecting the district's transformation from a predominantly rural area to a more urbanized region. Cropland, which constituted the largest land use category in 2004 with 814.2 km² (63.214%), experienced significant fluctuations. By 2014, cropland had increased to 1,037.1 km² (80.523%), but by 2024, it had decreased sharply to 505.9 km² (39.28%). This overall decrease of 308.27 km² suggests a shift away from agricultural land use, possibly due to urban expansion, changes in agricultural practices, or land degradation.
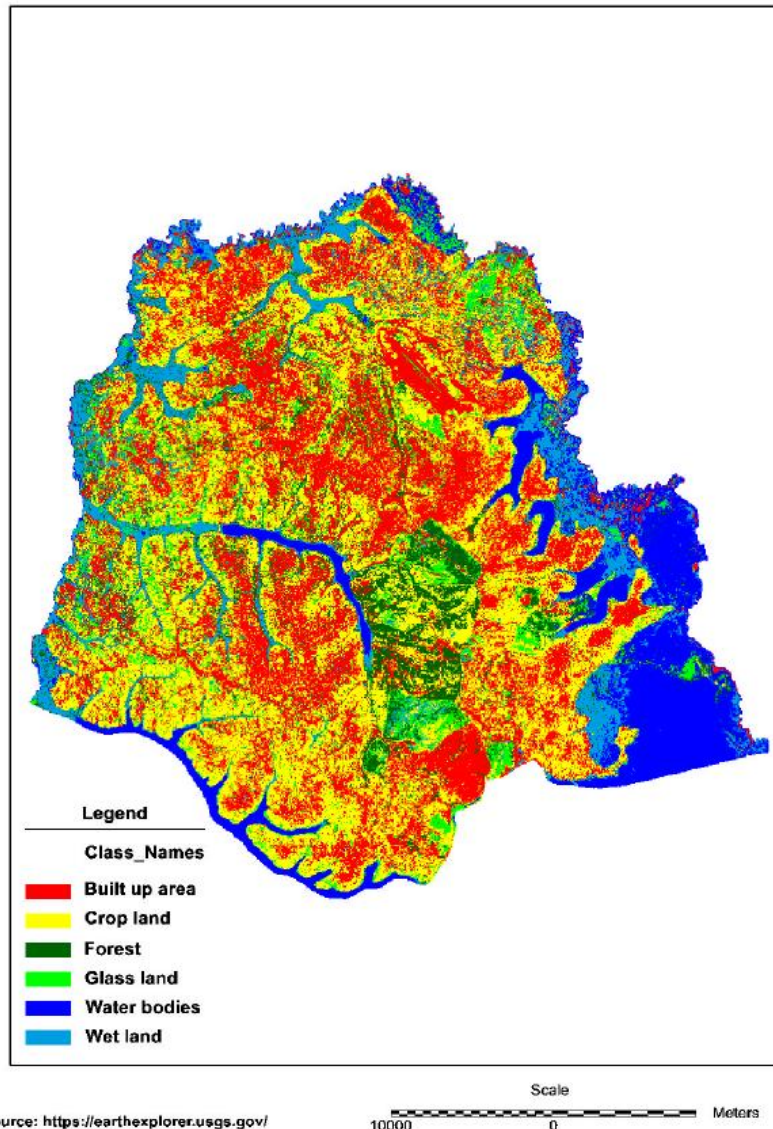
Figure 2: Bugesera District Land Use and Land Cover Change 2004

Forest areas showed an initial decline from 99.4 km² (7.718%) in 2004 to 40.5 km² (3.145%) in 2014, followed by a substantial increase to 338.9 km² (26.309%) in 2024. This net increase of 239.45 km² indicates successful reforestation efforts and conservation initiatives. Grassland areas, on the other hand, decreased from 315.0 km² (24.457%) in 2004 to 141.5 km² (10.989%) in 2014, with a slight recovery to 193.0 km² (14.982%) in 2024. The overall decrease of 122.04 km² suggests a reduction in open grazing areas, possibly due to land conversion for other uses. Water bodies and wetlands also experienced notable changes. Water bodies decreased slightly from 4.5 km² (0.352%) in 2004 to 3.5 km² (0.273%) in 2014, but increased to 11.6 km² (0.901%) in 2024. This net increase of 7.07 km² may be attributed to water conservation projects and the creation of artificial lakes or reservoirs. Wetlands decreased marginally from 52.2 km² (4.055%) in 2004 to 50.7 km² (3.934%) in 2014, but increased significantly to 84.2 km² (6.534%) in 2024. The net increase of 31.93 km² highlights the importance of wetland restoration and protection efforts.

Figure 3: Bugesera District Land Use and Land Cover Change 2024

Land use changes in Bugesera District driven by agricultural expansion, urbanization, and settlement growth have significantly affected ecosystem services, notably degrading water quality, reducing biodiversity, diminishing carbon sequestration capacity, altering economic livelihoods, and weakening environmental protection efforts. Respondents overwhelmingly reported that these land use changes have led to water contamination from fertilizers, pesticides, and waste, along with declining biodiversity due to habitat loss and fragmentation. The conversion of forests into farmlands and urban spaces has sharply reduced carbon absorption, with 100% of respondents agreeing that urban expansion has eliminated vegetative cover. Economically, while agricultural and urban developments have improved incomes and created new job opportunities, they have also displaced traditional livelihoods and strained local natural resources. Environmental protection and natural resource management have suffered due to overexploitation and inadequate policy responses, reflecting a common global challenge where rapid land development surpasses the capacity for sustainable governance.

Table 2: Coefficients Table

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	3.794	.389		9.754	.000
	Land for Agriculture	-.061	.034	-.177	-1.780	.078
	Urbanization	.077	.044	.183	1.753	.083
	Population and settlement growth	.088	.042	.209	2.100	.038
	Economic activities and infrastructures	.010	.039	.027	.265	.792
a. Dependent Variable: Dependent Variable: ecosystem services						

Source: Primary Data, 2025

The coefficients table .2 provides detailed insights into the relationship between the independent variables (land use changes) and the dependent variable (ecosystem services). The constant value (intercept) of the equation is 3.794, which represents the baseline level of ecosystem services when all independent variables are equal to zero. For the individual predictors, land for agriculture has a negative coefficient of -0.061, suggesting that an increase in agricultural land area tends to reduce ecosystem services. However, this relationship is not statistically significant at the 0.05 level ($p = 0.078$), meaning that the impact of agricultural land on ecosystem services could be due to random variation rather than a real effect. Similarly, urbanization has a positive coefficient of 0.077, indicating that urbanization tends to increase ecosystem services, but the relationship is also not statistically significant at the 0.05 level ($p = 0.083$).

Population and settlement growth, with a coefficient of 0.088, shows a positive impact on ecosystem services. This relationship is statistically significant at the 0.05 level ($p = 0.038$), suggesting that population and settlement growth contributes positively to ecosystem services in the Bugesera District. Economic activities and infrastructures have a very small positive coefficient of 0.010, but it is not statistically significant ($p = 0.792$), indicating that this variable does not significantly impact ecosystem services when considered in the context of the other factors.

The linear equation representing the model, based on the coefficients, can be written as:

Ecosystem Services = 3.794 − 0.061 (Land for Agriculture) + 0.077 (Urbanization) + 0.088 (Population and Settlement Growth) + 0.010 (Economic Activities and Infrastructures)

In conclusion, the study hypotheses are evaluated as follows: the hypothesis that land use change impacts ecosystem services are supported, but the specific role of land for agriculture and urbanization remains unclear, as neither shows a statistically significant effect. However, population and settlement growth is found to have a significant positive impact on ecosystem services, supporting the hypothesis that such growth influences ecosystem service levels. The hypothesis regarding economic activities and infrastructure development, however, is rejected, as this factor does not significantly affect ecosystem services. Thus, while the overall relationship between land use change and ecosystem services in Bugesera District is statistically significant, the individual impacts of some land use activities, like agriculture and urbanization, are less clear, requiring further exploration in future studies.

Discussion of results

Over the past two decades, Bugesera District has experienced extensive agricultural expansion driven by population growth, food demand, and policy-driven economic goals. This pattern, while supporting local food security and improving livelihoods, has led to notable environmental degradation including soil depletion, water scarcity, and habitat loss. These trends echo findings from Biazin et al. (2020), who observed similar dynamics in sub-Saharan Africa, where agricultural intensification is fueled by demographic pressures and economic incentives. However, despite its benefits, the expansion of farmland in Bugesera has compromised key ecosystem services, as shown by the degradation of natural habitats and biodiversity loss. The reliance on unsustainable farming practices such as overuse of chemicals has further intensified environmental stress.

Simultaneously, rapid urbanization in Bugesera has transformed the district's ecological landscape, contributing to pollution, biodiversity fragmentation, and a decline in carbon sequestration capacity. The conversion of forests and wetlands into urban settlements has led to increased runoff, waste accumulation, and pressure on freshwater sources. The study aligns with the findings of Abdul-Rahman et al. (2021), who documented the environmental costs of urban growth in developing regions, including deteriorating water and air quality. As natural ecosystems are replaced with built environments, Bugesera faces challenges common to urbanizing regions in Africa—namely, how to accommodate growth without undermining ecological stability. These urban pressures compound existing issues from agricultural expansion, creating a need for integrated, sustainable planning.

The intersection of population growth, economic transition, and land use changes in Bugesera has exacerbated pressures on natural resources such as water, soil, and biodiversity. Studies like those by Mbah et al. (2022) and Assefa et al. (2021) corroborate these findings, showing that rapid settlement growth increases demand for limited resources and degrades their quality. Additionally, carbon sequestration has declined due to forest loss, mirroring concerns raised by Kiros et al. (2020). While economic activities have diversified, many traditional livelihoods have been displaced, reflecting broader trends across East Africa (Tadesse et al., 2020). These multifaceted changes highlight the urgent need for sustainable land and resource management strategies in Bugesera. As suggested by comparative studies, long-term resilience will depend on policies that balance environmental conservation with socio-economic development (Abdul-Rahman et al., 2021; Biazin et al., 2020).

Conclusion

In conclusion, the study highlights the significant and far-reaching impacts of land use changes in Bugesera District on various ecosystem services. The expansion of agriculture, urbanization, and population growth have all played pivotal roles in altering the district's land cover and, consequently, its natural environment. These changes have led to declines in water quality, loss of biodiversity, reduced carbon sequestration capacity, and challenges in managing natural resources. The study's findings strongly support the hypothesis that land use changes have a considerable impact on ecosystem services in the region, emphasizing the need for sustainable land management practices and policies that balance development with environmental conservation. The results underscore the urgency for targeted interventions to mitigate the adverse effects of these land use changes on the ecosystem and ensure the long-term sustainability of the region's resources.

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