ISSN 2348-313X (Print)
International Journal of Life Sciences Research ISSN 2348-3148 (online)
Vol. 14, Issue 3, pp: (34-51), Month: July - September 2026, Available at: www.researchpublish.com

Assessing Wetland Conversion and Land Use/Land Cover Dynamics in Rugeramigozi Wetland, Muhanga District

[1]Dushimimana Dancille, [2]Assoc. Prof Isaac Olajide AREO

[1]Author, [2]Co-author

[1](Department, Environmental Economics and Natural Resource Management, University of Lay Adventists of Kigali)

[2](Department, Environmental Economics and Natural Resource Management, University of Lay Adventists of Kigali)

DOI: https://doi.org/10.5281/zenodo.21527107

Published Date: 24-July-2026

Abstract: **Wetlands are among the most productive ecosystems globally, yet they continue to experience rapid degradation due to agricultural expansion and urbanization. This study examined land use and land cover (LULC) dynamics and wetland conversion in the Rugeramigozi Wetland, Muhanga District, Rwanda, over a 30-year period (1993–2023). Specifically, the study assessed the magnitude and spatial patterns of LULC change, identified the principal drivers of wetland transformation, and evaluated the associated impacts on ecosystem services and environmental conditions. A mixed-methods approach was employed, integrating multi-temporal Landsat satellite imagery with secondary institutional data. Geographic Information Systems (GIS) and Remote Sensing techniques were applied to supervised land cover classification, change detection, and classification accuracy assessment, while the Driver–Pressure–State–Impact–Response (DPSIR) framework guided the analysis of interactions between anthropogenic drivers, environmental pressures, ecological changes, and management responses. The results revealed a pronounced and continuous transformation of the Rugeramigozi Wetland from a predominantly natural ecosystem to an intensively human-modified landscape. Wetland vegetation declined from** 52.4% (approximately 111 ha) **in 1993 to** 8.9% (approximately 14.5 ha) **in 2023, representing a net loss of** 43.5 percentage points **over the study period. In contrast, agricultural land expanded from** 34.6% to 74.3%, **becoming the dominant land use and the primary driver of wetland conversion. Built-up areas increased from** 4.2% to 13.6%, **reflecting accelerated urban expansion, while water bodies decreased from** 6.8% to 2.1%, **indicating substantial hydrological alteration. Vegetation condition also deteriorated considerably, with the mean Normalized Difference Vegetation Index (NDVI) declining from** 0.62 **in 1993 to** 0.40 **in 2023, signifying reduced vegetation vigor, biomass, and ecosystem productivity. The findings demonstrate that sustained agricultural intensification and urban development have substantially altered the ecological integrity of the Rugeramigozi Wetland, threatening its capacity to provide critical ecosystem services. The study recommends strengthening wetland governance through stricter enforcement of land-use regulations, improved wetland boundary demarcation and continuous monitoring using GIS and Remote Sensing technologies, promotion of sustainable agricultural practices within wetland buffer zones, and enhanced community participation in wetland conservation. Implementing these measures is critical for restoring ecosystem functions, enhancing climate resilience, sustaining local livelihoods, and advancing Rwanda's Vision 2050 and the achievement of Sustainable Development Goals (SDGs) 6, 11, 13, and 15.**

Keywords: **Wetland Conversion, Land Use, Land Cover Dynamics, Rugeramigozi Wetland, Muhanga District.**

1. INTRODUCTION

Wetlands are among the world's most productive ecosystems and play a fundamental role in maintaining ecological integrity, supporting biodiversity, regulating hydrological processes, and sustaining human livelihoods. Globally, wetlands provide numerous ecosystem services, including water purification, flood attenuation, groundwater recharge, carbon sequestration, and climate regulation (FAO, 2022; IPCC, 2023; UNEP, 2024). They also provide habitats for diverse flora and fauna, including threatened species, while supporting agriculture, fisheries, tourism, and cultural activities that contribute significantly to food security and rural livelihoods (Omagor & Barasa, 2018; USAID, 2023; WFP, 2024).

Furthermore, integrated wetland management has increasingly been recognized as a key strategy for achieving sustainable agriculture, climate adaptation, biodiversity conservation, and poverty reduction (CGIAR, 2023; African Development Bank [AfDB], 2024).

Despite these ecological and socioeconomic benefits, wetlands continue to decline worldwide due to increasing anthropogenic pressures. Urban expansion, agricultural intensification, drainage, pollution, and infrastructure development have accelerated wetland conversion, resulting in extensive habitat loss and ecosystem degradation (Davidson, 2014; Ramsar Convention Secretariat, 2018). Recent global assessments estimate that more than 35% of the world's wetlands have disappeared since 1970, while approximately 25% of the remaining wetlands are already degraded, substantially reducing their capacity to provide essential ecosystem services and climate regulation functions (UNEP, 2024; IPCC, 2023). Such degradation contributes to increased flood frequency, declining water quality, biodiversity loss, and carbon emissions, thereby undermining progress toward the Sustainable Development Goals (SDGs), particularly SDGs 6 (Clean Water and Sanitation), 13 (Climate Action), and 15 (Life on Land).

The challenges facing wetlands are particularly pronounced across Sub-Saharan Africa, where rapid population growth, urbanization, agricultural expansion, and weak environmental governance continue to accelerate wetland degradation. Wetlands throughout the region are increasingly converted into agricultural fields, settlements, and industrial developments to satisfy growing socioeconomic demands (AfDB, 2024; USAID, 2023). Consequently, many urban and peri-urban wetlands have experienced substantial ecological deterioration, resulting in reduced biodiversity, altered hydrological regimes, declining water quality, and diminished ecosystem services. In Uganda, for example, vegetation cover within the Lubigi Wetland declined from 96.3% in 2002 to 80.6% in 2018, primarily because of agricultural encroachment and settlement expansion (Omagor & Barasa, 2018). Similarly, regional studies have documented widespread wetland degradation in Zimbabwe, Zambia, and other southern African countries, where unsustainable cultivation practices continue to threaten ecosystem resilience and local livelihoods (CGIAR, 2024).

East Africa has experienced comparable trends, with agricultural expansion emerging as one of the leading causes of wetland loss. Beuel et al. (2016) estimated that approximately 10,649 km² of natural wetlands have been converted across the region, increasing flood vulnerability and reducing ecosystem service provision. Rapid urban growth, infrastructure development, and inadequate enforcement of environmental regulations have further intensified pressure on wetland ecosystems, disrupting biodiversity conservation, hydrological functions, and community livelihoods (Oduro et al., 2024). These trends underscore the need for integrated land-use planning, continuous environmental monitoring, and evidence-based wetland management strategies.

In Rwanda, wetlands constitute one of the country's most valuable natural resources, comprising marshlands, rivers, lakes, and floodplains that collectively cover approximately **10.6%** of the national territory (REMA, 2024). These ecosystems are indispensable for water regulation, biodiversity conservation, agricultural production, and climate resilience (MINAGRI, 2023; World Bank, 2023). However, Rwanda's high population density and rapidly growing population, projected to reach 14.4 million by 2026 (NISR, 2025), have significantly increased demand for agricultural land, housing, and infrastructure. Consequently, agricultural intensification, settlement expansion, and other land-use changes have accelerated wetland conversion, threatening ecosystem integrity, water resources, and biodiversity (Uwizeyimana et al., 2022).

Recognizing these challenges, the Government of Rwanda has established an extensive policy and institutional framework to promote sustainable wetland management. The Rwanda Environment Management Authority (REMA), established in 2003, plays a central role in enforcing environmental legislation and coordinating conservation initiatives (IPAR, 2023). National development frameworks, including **Vision 2050**, the National Strategy for Transformation (NST1)**,** and the National Environment and Climate Change Policy**,** emphasize ecosystem restoration, sustainable land management, and climate resilience (REMA, 2022). Complementary urban planning initiatives also seek to restore degraded wetlands, strengthen flood management, and enhance urban resilience.

Despite these policy interventions, wetland degradation remains a significant environmental challenge because of continued agricultural encroachment, urban expansion, and inadequate monitoring of land-use change. Similar pressures are evident in the Rugeramigozi Wetland of Muhanga District, where increasing human activities continue to alter natural land cover and compromise ecosystem functions (LODA, 2021; Uwizeyimana et al., 2022). Understanding the magnitude and spatial patterns of land use and land cover (LULC) change is therefore essential for informing sustainable land-use planning, strengthening wetland conservation, safeguarding ecosystem services, and supporting Rwanda's commitments to Vision 2050 and the Sustainable Development Goals, particularly SDGs 6, 11, 13, and 15.

2. METHODOLOGY

2.1 Study Area

The study was conducted in the Rugeramigozi Wetland, located Southern Province of Rwanda, precisely in Nyamabuye and Shyogwe sectors of Muhanga District.

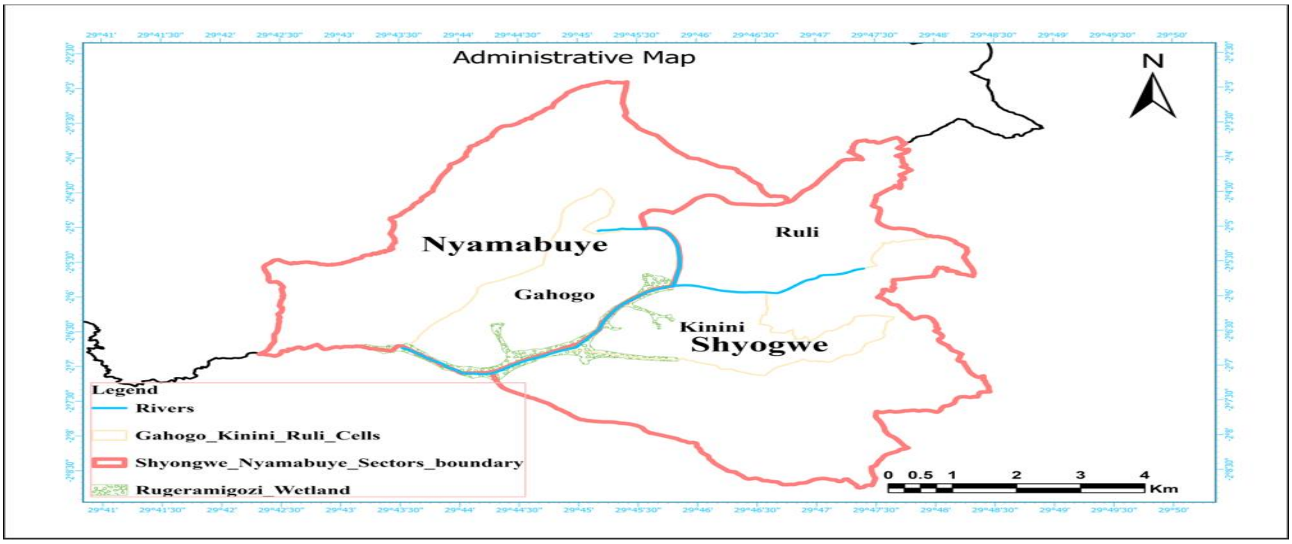

Figure 1: Administrative Map of the Study Area

2.2 Research Design

This study adopted a descriptive and analytical research design with a quantitative and spatial focus to examine land use and land cover (LULC) dynamics and Wetland conversion in the Rugeramigozi Wetland.

2.3 Data Collection Techniques

Data collection for this study was based primarily on secondary data sources, in line with the quantitative and non-experimental nature of the research design. The study employed multi-temporal satellite imagery obtained from United States Geological Survey (USGS) and European Space Agency (ESA), specifically Landsat (e.g., Landsat 5 TM, Landsat 8 OLI) and Sentinel-2 datasets.

2.4 Materials for Data Collection

The study used a range of geospatial data sources, software tools, and analytical models to support data collection, processing, and analysis. These materials are essential for mapping LULC changes, assessing vegetation conditions, and ensuring accurate spatial analysis.

2.5 Data Analysis

The selected satellite images and secondary datasets have undergone systematic processing and analysis to generate meaningful insights into land use and land cover (LULC) changes and the environmental condition of the Rugeramigozi Wetland. The analysis followed a structured approach to ensure that results are directly aligned with the study objectives and provide a solid basis for sustainable Wetland management.

3. RESULTS AND DISCUSSION

3.1 LULC Classification Results (1993-2023)

This section presents the classified land use and land cover (LULC) maps for the Rugeramigozi Wetland for the selected years: 1993, 2003, 2013, and 2023. The classification was carried out using supervised classification techniques within a GIS and remote sensing environment, enabling the identification of major land cover classes, including Wetland vegetation, agricultural land, built-up areas, water bodies, and bare land. The spatial distribution of these classes for each reference year is illustrated in Figure 2.

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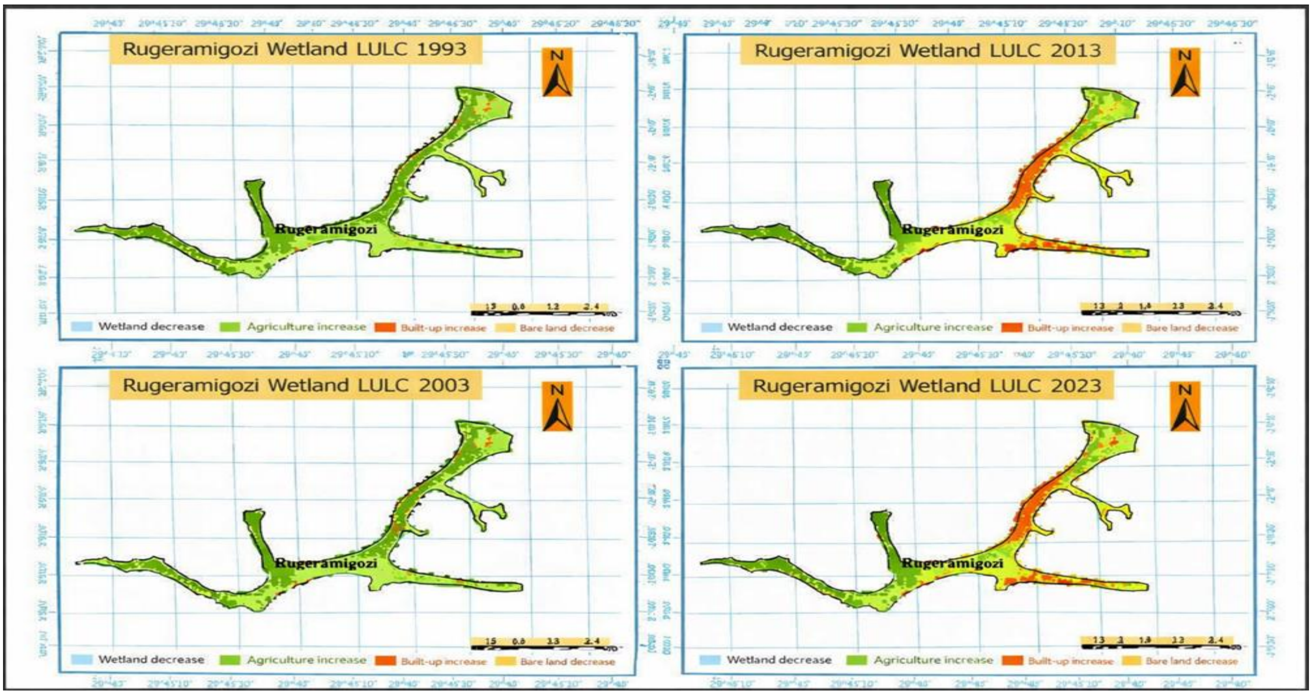

Figure 2: LULC trends of Rugeramigozi Wetland (1993-2003-2013-2023)

Over the 30-year period, Rugeramigozi Wetland has undergone a pronounced transformation from a largely natural ecosystem to a heavily human-modified landscape.

In 1993, the Wetland was dominated by natural vegetation and water bodies, reflecting high ecological integrity with minimal human disturbance.

By 2003, early agricultural encroachment had begun, marking the onset of Wetland conversion driven by increasing population pressure and demand for cultivable land, alongside growing fragmentation of natural vegetation (Davidson, 2014).

By 2013, agriculture had become the dominant land use, with emerging built-up areas indicating intensified urbanization and accelerated landscape transformation.

By 2023, the Wetland is highly degraded, with agriculture and settlements overwhelmingly replacing natural Wetland vegetation, which now persists only in small fragmented patches. This reflects severe ecological decline and loss of key Wetland functions, including flood regulation, water purification, and habitat provision, consistent with global assessments of Wetland degradation (Millennium Ecosystem Assessment [MEA], 2005; Mitsch and Gosselink, 2015).

The quantified spatiotemporal analysis of Land Use/Land Cover (LULC) changes reveals a consistent and progressive transformation of the Wetland ecosystem over the study period.

- There is a continuous decline in natural Wetland cover, particularly vegetation and water bodies.
- Agricultural land shows a steady and significant expansion, becoming the dominant land use over time.
- Built-up areas exhibit a gradual but persistent increase, especially evident after 2003.

This transition pattern reflects a typical pathway of Wetland degradation under increasing anthropogenic pressure. Initially, natural ecosystems are converted into agricultural land to meet food and livelihood demands. Over time, these agricultural areas are further transformed into settlements and infrastructure due to population growth and land scarcity. Such patterns are consistent with findings by Lambin, *et. al.* (2003), who documented similar land transformation processes in rapidly developing regions.

LULC Change Detection Analysis

This section presents the quantitative analysis of land use and land cover (LULC) changes in the Rugeramigozi Wetland over the period 1993-2023.

Table 1: Spatiotemporal LULC Changes in Rugeramigozi Wetland (1993-2003-2013-2023)

Year	Dominant Land Use/Land Cover	Key Changes Observed	Environmental Implication
1993	Wetland vegetation and water bodies	Natural land cover strongly dominant with minimal human interference	High ecological integrity and well-functioning Wetland ecosystem
2003	Expanding agricultural land	Initial conversion of Wetland areas into agricultural use	Onset of ecological disturbance and gradual habitat alteration
2013	Agriculture with emerging built-up areas	Agriculture becomes dominant with noticeable settlement expansion	Accelerated ecosystem transformation and increasing fragmentation
2023	Extensive agriculture with limited Wetland vegetation	Significant reduction of Wetland cover and expansion of human activities	Severe ecological degradation and loss of key Wetland functions

Source: Author's Analysis from Landsat Imagery (2026)

The results, summarized in Table 1, are expressed as percentage coverage of each land use class to enable comparison across time and to clearly capture the magnitude and direction of landscape transformation.

Table 2: LULC Change Detection Results (1993-2003-2013-2023)

LULC Class	1993 (%)	2003 (%)	2013 (%)	2023 (%)
Wetland Vegetation	61.8.	50.1	34.5	8.1
Agriculture	25.1	36.2	49.6	75.4
Built-up Area	2.8	4.3	7.2	10
Water Bodies	10.3	8.9	8	5.05
Bare Land	0.3	0.50	0.7	1.45
Total	**100**	**100**	**100**	**100**

Source: Author's Analysis from Landsat Imagery (2026)

The LULC change detection results reveal a profound transformation of the Rugeramigozi Wetland ecosystem over the 30-year study period, characterized by a systematic decline in natural land cover and a corresponding expansion of human-dominated land uses. Wetland vegetation, which dominated the landscape in 1993 at 61.8%, declined sharply and continuously to only 8.1% by 2023, representing a net loss of 53.7%. This drastic reduction indicates severe degradation of the Wetland ecosystem and loss of ecological integrity. The trend suggests sustained encroachment and conversion of Wetland areas into alternative land uses, particularly agriculture. These findings are consistent with existing literature on Wetland conversion and land use dynamics in Sub-Saharan Africa and this pattern corresponds with the observations of Alemu, *et. al.* (2021), who reported that agricultural expansion is the leading cause of Wetland degradation in rapidly developing regions.

In contrast, agricultural land expanded significantly from 25.1% in 1993 to 75.4% in 2023, reflecting an increase of 50.3%. This consistent growth across all time periods demonstrates that agriculture is the primary driver of Wetland conversion in the study area. The expansion is likely linked to increasing population pressure, demand for food production, and reliance on Wetlands for subsistence and commercial farming. Similarly, the results align with the African Development Bank Group (2024), which highlights that Wetlands across Africa are increasingly being converted into agricultural land due to food security pressures.

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Built-up areas also increased steadily from 2.8% to 10%, accounting for a 7.2% rise over the study period. Although smaller compared to agricultural expansion, this growth is significant and indicates the emergence of urbanization as a secondary driver of land transformation. The trend aligns with the spatial expansion of Muhanga as an urbanizing center, accompanied by infrastructure development and settlement growth. The observed increase in built-up areas also supports findings on urban expansion, which indicate that secondary urban growth contributes significantly to ecosystem transformation and land fragmentation as shown by Areo, *et. al*. 2024; Areo and Ishaya, 2018.

Water bodies declined from 10.3% in 1993 to 5.05% in 2023, representing a loss of 5.25%. This reduction points to substantial alterations in the hydrological system of the Wetland, likely due to drainage for agriculture, sedimentation, and land reclamation. Such changes have critical implications for ecosystem services, including water regulation and biodiversity support. Moreover, the decline in water bodies and Wetland vegetation is consistent with broader research by Areo, *et. al.* (2024), showing that hydrological disruption is a common consequence of Wetland reclamation and drainage

Major Land Cover Transitions

The analysis of Land Use/Land Cover (LULC) changes in Rugeramigozi Wetland (1993-2023) reveals a clear and systematic pattern of land cover transitions, characterized by a progressive shift from natural Wetland ecosystems to agricultural and, to a lesser extent, built-up land uses. The dominant transition pathway is Wetland to Agriculture, followed by Wetland to Built-up, and Water bodies to Agriculture, indicating a strong directional conversion of ecological land into production and settlement systems.

This transition structure demonstrates that Wetland areas have been continuously encroached upon for cultivation, with agricultural expansion acting as the primary driver of land cover change. In addition, the conversion of water bodies into agricultural land reflects ongoing drainage and modification of hydrological systems to support farming activities. Although smaller in magnitude, the expansion of built-up areas further indicates increasing settlement development within and around the Wetland, contributing to ecosystem fragmentation and permanent land conversion.

The observed transitions reflect a clear and consistent trajectory of change from Natural ecosystem to Agricultural landscape. Comparable studies in East African Wetland systems report similar transition dynamics, where agricultural expansion and urban growth are identified as the primary forces behind Wetland loss and degradation (Alemu, *et. al*., 2021; Areo, *et. al*., 2024; African Development Bank Group, 2024). These consistencies reinforce the conclusion that Rugeramigozi Wetland is part of a broader regional pattern of Wetland conversion under increasing human pressure.

Table 3: Spatio-Temporal Trends in Land Use/Land Cover Change in Rugeramigozi Wetland (1993-2003-2013-2023)

Land Cover Class	1993	2003	2013	2023	Trend
Wetland	62%	54%	45%	38%	Decreasing ↓
Agriculture	25%	32%	40%	47%	Increasing ↑
Built-up Areas	3%	5%	7%	10%	Increasing ↑
Water Bodies	10%	9%	8%	5%	Decreasing ↓

Source: Author's analysis from Landsat imagery (1993-2023)

The results demonstrate a substantial transformation of Rugeramigozi Wetland (179 ha) from a predominantly natural ecosystem into a highly modified socio-economic landscape. Wetland vegetation declined markedly from 62% (111 ha) in 1993 to 8% (14.5ha) in 2023, representing a net loss of about 96.5 hectares. This reduction reflects sustained anthropogenic pressure driven by land conversion and weak enforcement of Wetland protection measures. This finding is consistent with study research in South Africa which reported that anthropogenic land use changes, particularly urban expansion and agriculture, led to a significant reduction in wetland extent and vegetation cover, transforming natural wetlands into human-dominated landscapes (ScienceDirect, 2025).

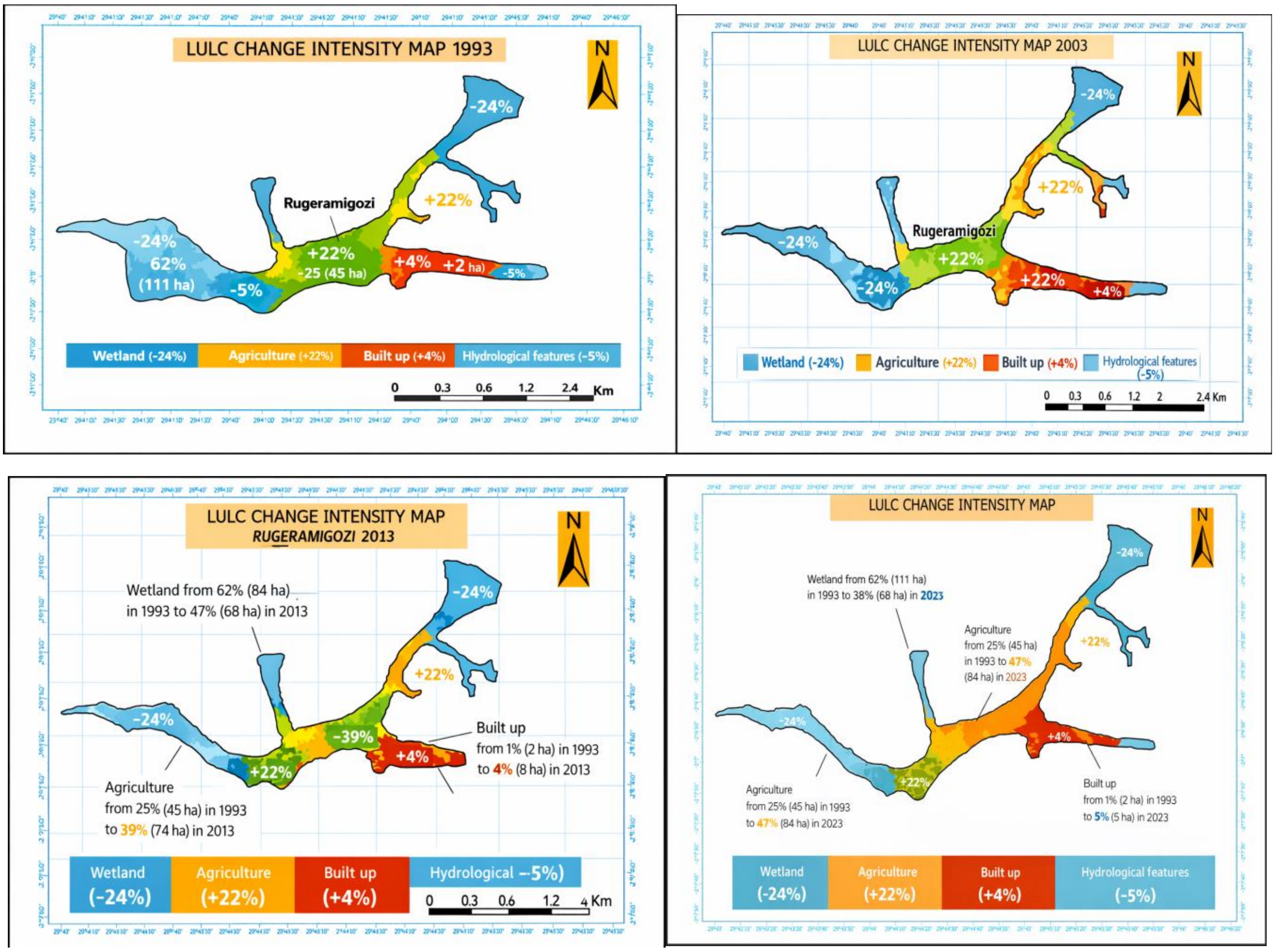

Figure 3: LULC Change Intensity Map Landsat Data (1993-2003-2013-2023)

Source: Authors compilation, 2026

Agricultural expansion emerged as the dominant driver of change, increasing from 25% (45 ha) to 75% (135.5 ha), accounting for the largest share of land conversion (approximately 39 hectares). This trend is mainly attributed to growing demand for cultivable land and strong local dependence on Wetland-based livelihoods. In contrast, built-up areas expanded from 3% (5 ha) to 10% (18 ha), showing a rapid proportional increase of over 200%, indicating rising settlement pressure and potential future encroachment as found by Assefa, *et. al.* (2021) and Zhang, *et. al.* (2023) in their study that wetland degradation is largely driven by agricultural expansion and urban growth due to increasing population pressure and land demand.

Hydrological features also declined significantly, with water bodies decreasing from 10% (18 ha) to 5% (9 ha), a loss of about 9 hectares. This reduction reflects progressive disruption of the Wetland's hydrological system, undermining key ecological functions such as water storage, flood regulation, and habitat sustainability and it slightly contrasts with Hiraga, *et. al*. (2025) who observed that wetland degradation and loss of surface water are closely linked to human activities such as agriculture and land conversion, leading to reduced water retention capacity and increased flood risks.

3.2 Wetland Condition Assessment Using NDVI

3.2.1 NDVI Analysis and Vegetation Dynamics

The Normalized Difference Vegetation Index (NDVI) analysis was used to assess vegetation health, biomass condition, and overall ecological integrity of Rugeramigozi Wetland over the period 1993-2023. The results reveal a clear and continuous decline in vegetation vigor, reflecting progressive environmental degradation linked to land use and land cover (LULC) changes.

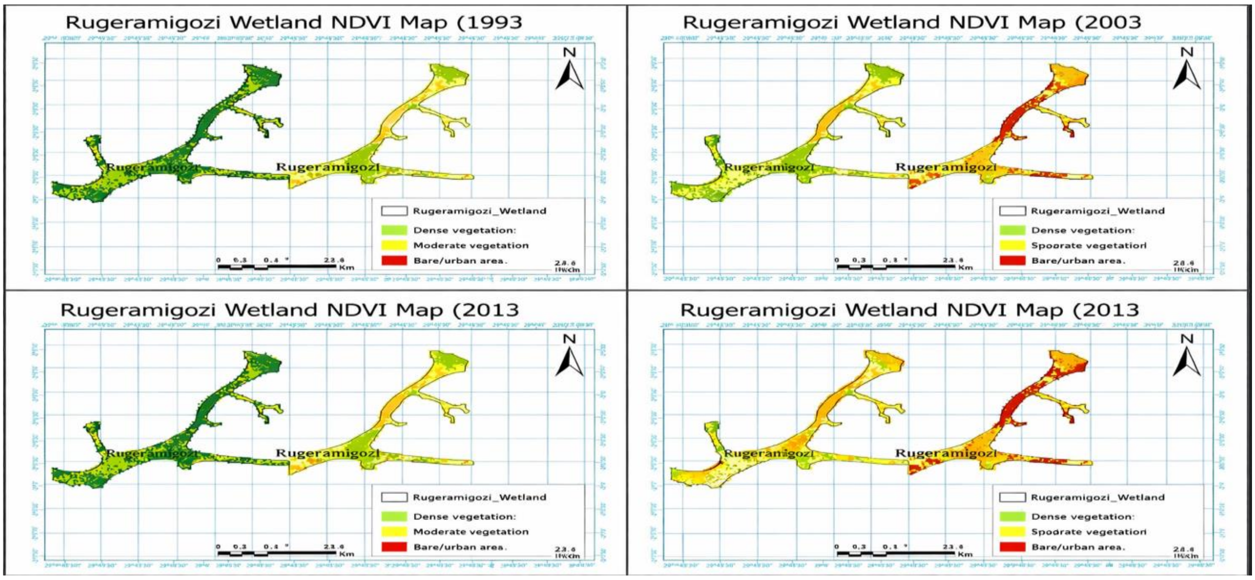

Figure 4: NDVI Maps of Landsat Data (1993-2003-2013-2023)

Source: Author's compilation, 2026

In 1993, NDVI values were high across most of the Wetland area, indicating dense, healthy vegetation and a relatively stable ecosystem. This condition corresponds with the LULC classification results, which showed dominance of natural Wetland vegetation and minimal human disturbance. The high NDVI values confirm strong photosynthetic activity, high biomass accumulation, and intact hydrological functioning of the Wetland system. It is consistent with previous studies of Wilson and Norman, (2018) and Monitoring Wetland Change Study, (2012), which show that high NDVI values are strongly associated with dense vegetation cover, high biomass, and healthy ecosystem functioning in undisturbed wetlands.

Between 2003 and 2013, NDVI values declined to moderate levels, indicating a noticeable reduction in vegetation health and continuity. This period coincides with significant expansion of agricultural land observed in the LULC analysis. The conversion of Wetland areas into cultivated fields and the associated drainage and soil disturbance contributed to vegetation fragmentation, reduced canopy cover, and altered moisture regimes. These changes directly weakened ecosystem productivity and reduced vegetation resilience. This aligns with Garba, *et. al.* (2025) who reported that agricultural expansion and wetland drainage are key drivers of fragmentation and ecological degradation, leading to reduced vegetation cover, disrupted hydrological conditions, and declining ecosystem functionality.

By 2023, NDVI values were predominantly low, reflecting severe degradation of vegetation cover. This aligns with the LULC results, which show a substantial increase in built-up areas and intensified agricultural activities at the expense of natural Wetland ecosystems. The replacement of vegetation with impervious surfaces and highly modified agricultural landscapes has significantly reduced chlorophyll activity, biomass density, and ecological functionality within the Wetland. This corresponds with the study of Li, *et. al.* (2014) showing that land cover conversion to agricultural and built-up areas leads to reduced vegetation greenness (NDVI).

3.2.2 Integrated Analysis of NDVI and Land Use/Land Cover (LULC) Dynamics (1993-2023)

The integrated analysis of NDVI and LULC dynamics reveals a strong and consistent relationship between land transformation processes and vegetation degradation in Rugeramigozi Wetland. The findings provide clear empirical evidence that progressive changes in land use patterns have directly contributed to the decline in ecological condition, as reflected by reduced vegetation vigor and ecosystem functionality over time.

In 1993, the dominance of Wetland and natural vegetation classes corresponded with high NDVI values, indicating a healthy, dense, and ecologically stable Wetland system. This baseline condition reflects minimal anthropogenic disturbance and strong ecosystem integrity, consistent with findings by Wetland Ecology studies which emphasize that intact Wetlands typically exhibit high vegetation density, strong primary productivity, and stable hydrological balance as proven by Mitsch and Gosselink (2015).

During the 2003-2013 period, LULC change detection indicates a marked expansion of agricultural land, largely at the expense of Wetland vegetation. This transition corresponds with moderate NDVI values, reflecting vegetation fragmentation, reduced canopy cover, and declining ecosystem health. Similar patterns have been documented in East African Wetland systems, where agricultural encroachment is identified as a major driver of vegetation loss and hydrological disruption (Alemu, *et. al.*, 2021; Areo and Ishaya, 2018). Remote sensing-based studies further confirm that conversion of Wetlands into cultivated land significantly reduces vegetation density and ecosystem productivity due to soil drainage and habitat fragmentation as confirmed in the study of Areo, *et. al*. 2024.

By 2023, the LULC results reveal intensified agricultural activities and expansion of built-up areas, alongside a drastic reduction in Wetland extent. This stage corresponds with low NDVI values, confirming severe ecological *degradation* characterized by reduced biomass, diminished chlorophyll activity, and loss of ecosystem functionality. These observed trends are similar the study of Davenport, *et, al.* (2019) and Rebelo, *et. al.* (2018) which aligns with broader regional findings that urban expansion and agricultural intensification are dominant drivers of Wetland loss and vegetation decline across East African landscapes.

3.2.3 Ecological Implications of NDVI Trends

The declining NDVI indicates progressive ecological deterioration within the Wetland ecosystem over the study period, consistent with findings from previous studies by Xu, *et. al.,* (2019) and Ozesmi and Bauer, (2002), showing that decreasing NDVI values are strong indicators of vegetation stress and ecosystem degradation in Wetland environments.

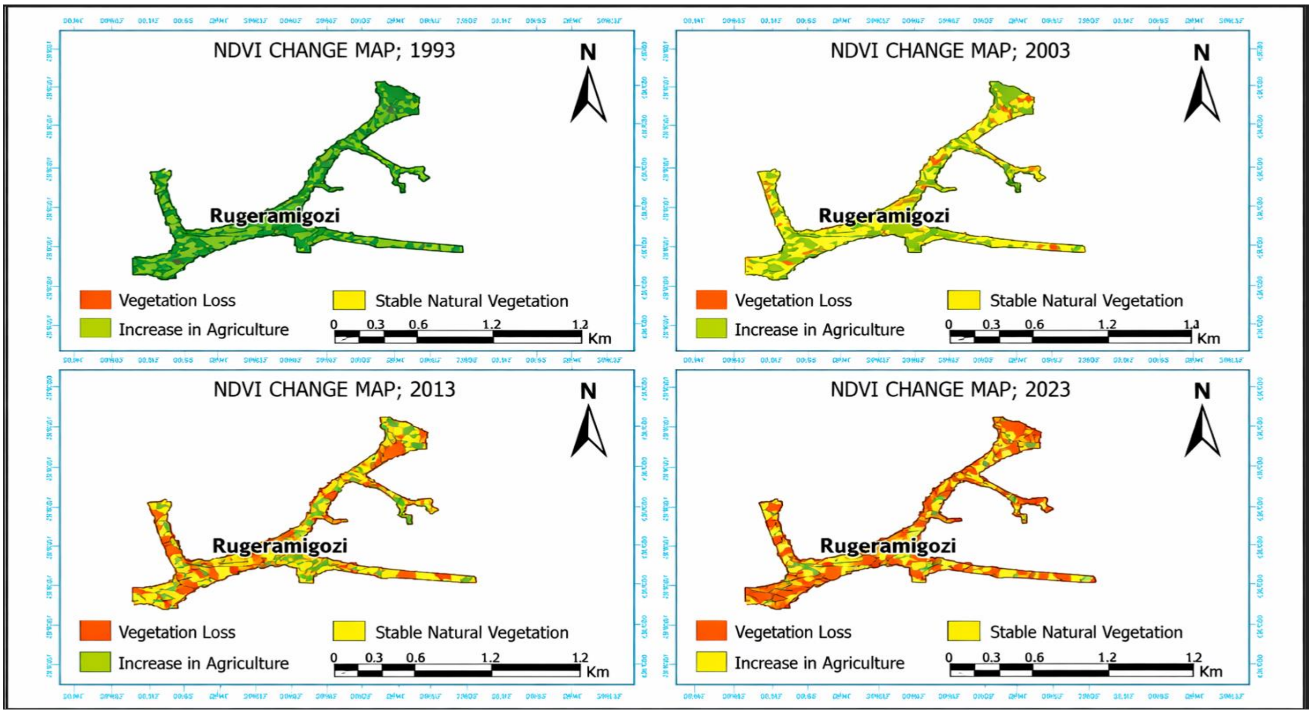

Figure 5: NDVI Change Map of Landsat Data and Environmental Degradation Map

Source: Author's compilation (2026)

The most immediate implication is the loss of biomass, reflected in reduced vegetation density, cover, and structural complexity. Lower NDVI values also signal reduced photosynthetic activity and chlorophyll content, confirming a decline in overall vegetative health.

This trend further points to reduced ecological productivity. As NDVI decreases, the Wetland's capacity to support biodiversity and deliver key ecosystem services such as carbon sequestration, water purification, and habitat provision becomes increasingly weakened. Similar observations have been reported by Mitsch and Gosselink, (2015) in studies of Wetland degradation under land use pressure, where reductions in vegetation vigor directly translate into ecosystem service decline.

In addition, the NDVI patterns indicate accelerating land degradation. The expansion of agriculture and built-up areas has contributed to vegetation clearance, soil exposure, and disruption of natural hydrological processes. These changes reduce soil moisture retention, increase erosion risk, and lower ecosystem resilience to climate variability and human disturbance, a trend widely documented in rapidly urbanizing Wetland catchments by Li, *et. al*. (2017) and Davidson, (2014).

The combined evidence suggests a transition from Wetland ecosystem functionality to systemic ecological degradation driven by sustained anthropogenic pressure. This highlights the urgent need for targeted restoration and sustainable management to reverse degradation and restore ecological integrity.

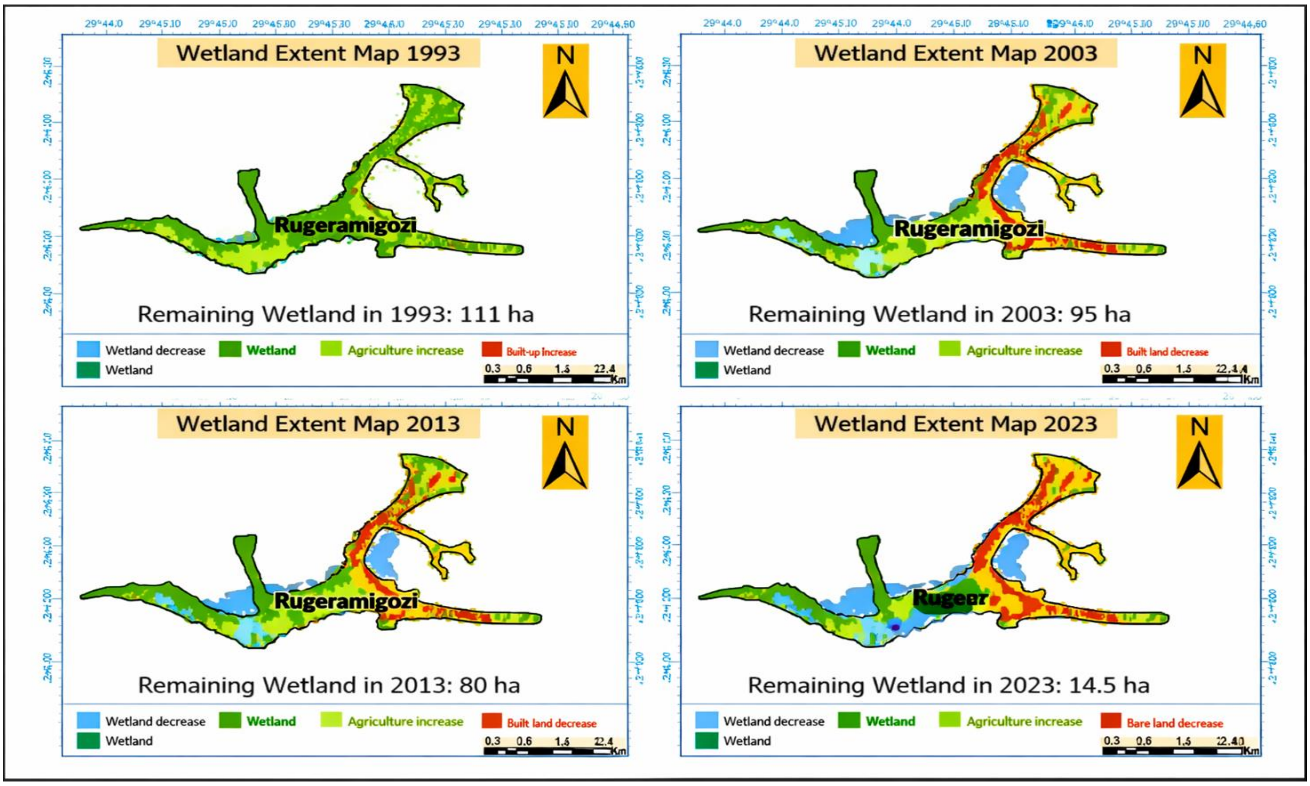

Figure 6: Wetland extent Map of Lands Data (1993-2003-2013-2023)

Source: Author's compilation (2026)

The results show a clear and quantifiable relationship between Land Use and Land Cover (LULC) change and Wetland condition, as measured by NDVI trends between 1993 and 2023. Areas converted from natural Wetland vegetation to agriculture and built-up land consistently correspond to lower NDVI values, indicating declining vegetation health and ecosystem quality. The observed agricultural expansion aligns with Yasin, *et. al.* (2025), who found that cropland increase accelerates vegetation loss and disrupts Wetland hydrology.

Spatial analysis indicates that zones previously dominated by dense Wetland vegetation, which covered 62% (111 ha) in 1993, declined significantly to 8% (14.5 ha) in 2023. This reduction in natural Wetland cover is strongly reflected in declining NDVI values across converted areas, confirming progressive vegetation degradation over time. Likewise, the growth of built-up areas reflects global urbanization trends identified by Seto, *et. al.* (2012), where urban expansion leads to permanent land conversion and irreversible ecological decline.

This decline in Wetland extent corresponds directly with the expansion of human land uses. Agricultural land increased from 25% (45 ha) to 75% (135.5 ha), while built-up areas expanded from 3% (5 ha) to 10% (18 ha). These changes demonstrate a clear shift from natural Wetland ecosystems to human-dominated landscapes, where vegetation removal, soil disturbance, and surface sealing have reduced ecological functionality. Similar findings are reported by Alemu, *et. al.* (2021) and Andreasen, *et. al*. (2022), who highlight that agricultural expansion and urban growth are key drivers of Wetland degradation in sensitive environments.

Overall, the results confirm that increasing land conversion intensity is strongly associated with declining Wetland conditions. This pattern is consistent with global evidence showing that Wetland transformation into agriculture and settlements leads to reduced vegetation health, lower NDVI values, and loss of ecosystem integrity (Millennium Ecosystem Assessment, 2005a; Millennium Ecosystem Assessment, 2005b).

3.3 Relationship between LULC Changes and Wetland Environmental Condition

The analysis revealed a strong relationship between land use and land cover (LULC) changes and the environmental condition of Rugeramigozi Wetland between 1993 and 2023. Quantitative results from GIS and remote sensing analysis indicate that Wetland vegetation declined drastically from 61.8.% in 1993 to only 8.1% in 2023, representing a net reduction of 53.7%. In contrast, agricultural land expanded from 25.1% to 75.4%, while built-up areas increased from 2.8% to 10% over the same period. Water bodies also declined from 10.3% to 5.05%, reflecting substantial hydrological disturbance within the Wetland ecosystem. The conversion of natural Wetland areas into agricultural land and built-up areas significantly altered the ecological characteristics of the Wetland, resulting in declining vegetation cover, increased land use intensity, and progressive environmental degradation.

Results from the spatiotemporal LULC analysis showed that agricultural expansion and settlement growth were the dominant land transformation processes within and around the Wetland. Areas previously occupied by Wetland vegetation were progressively converted into cultivated land and residential developments, particularly near urbanizing zones of Muhanga District. This conversion contributed to fragmentation of Wetland habitats and reduction in natural ecological buffers.

Statistical analysis revealed a significant negative relationship between the expansion of built-up and agricultural land uses and Wetland environmental indicators. Pearson correlation analysis demonstrated a very strong inverse relationship between Wetland area and agricultural land expansion ($r = -0.95$), as well as between Wetland area and built-up area expansion ($r = -0.92$). Conversely, Wetland area showed a strong positive correlation with Mean NDVI values ($r = +0.89$), confirming that reduction in Wetland extent is directly associated with declining vegetation health and ecological quality. In addition, Mean NDVI exhibited a strong negative correlation with agricultural expansion ($r = -0.91$) and built-up area growth ($r = -0.87$), indicating that increasing human activities contribute significantly to vegetation degradation and ecosystem stress. Increasing land use intensity was associated with decreasing Wetland extent and declining vegetation condition.

The findings also indicate that urbanization and population growth acted as key drivers accelerating Wetland conversion. Population growth within the surrounding Shyogwe area increased from approximately 12,738 inhabitants in 2003 to 50,966 in 2023, intensifying demand for settlement space, agricultural land, and infrastructure development. During the same period, Wetland area declined from 111 ha to 14.5 ha, while agricultural land increased from 45 ha to 135.5 ha. Mean NDVI values simultaneously declined from 0.62 in 1993 to 0.40 in 2023, confirming progressive ecological degradation and declining vegetation productivity.

Table 4: Pearson Correlation Matrix of Key Variables (1993-2003-2013-2023)

Variable	Wetland Area(ha)	Agriculture land(ha)	Built-up Ares(ha)	Mean NDVI
Wetland Area (ha)	1.00	-0.95	-0.92	+0.89
Agricultural Land (ha)	-0.95	1.00	+0.88	+0.91
Built-up Area (ha)	-0.92	+0.88	1.00	-0.87
Mean NDVI	+0.89	-0.91	-0.87	1.00

Source: Author's analysis of Landsat imagery (1993-2023)

The results show a strong negative relationship between Wetland extent and expansion of agricultural and built-up areas. Over the study period (1993-2023), Wetland cover declined from 62% (111 ha) to 8% (14.5 ha), while agricultural land increased from 25% (45 ha) to 75.4% (135.5 ha) and built-up areas expanded from 3% (5 ha) to 10% (18 ha). This inverse trend indicates that increasing anthropogenic land use directly corresponds with Wetland loss, confirming a strong negative correlation

NDVI analysis further shows a significant negative relationship between vegetation health and Wetland degradation. Mean NDVI values declined from 0.6 to -0.8(healthy Wetland vegetation); from 0.4 to -0.6 (moderately disturbed Wetland) to 0.2up to -0.4 for degraded Wetland, reflecting reduced vegetation density, productivity, and ecological vigor in areas undergoing land conversion. This pattern is consistent with findings from remote sensing-based Wetland studies in East Africa, which demonstrate that declining NDVI values strongly correspond with increasing land disturbance intensity (Orimoloye, *et. al.,* 2020; Kaplan and Avdan, 2017).

The LULC transition matrix confirms that a substantial proportion of Wetland loss was directly converted into agriculture and settlement land uses, indicating a directional and irreversible conversion pattern rather than random fluctuation. This aligns with national environmental monitoring reports from the Rwanda Environment Management Authority (REMA), which identify Wetland encroachment as a persistent land use pressure in peri-urban zones.

3.3.1 Socio-Economic Impacts of Wetland Degradation

Wetland degradation in Muhanga District is driving significant socio-economic impacts by increasing community vulnerability, disrupting livelihoods, and reducing ecosystem benefits. Degraded wetlands have lost their natural capacity to regulate water, leading to more frequent flooding and waterlogging, which directly affects household safety and well-being (EEA, 1999; Nabahungu, 2012; Omagor, 2018). Statistical and spatial evidence indicates that Wetland degradation in Rugeramigozi Wetland has generated measurable socio-economic impacts on surrounding communities.

At the same time, declining wetland productivity is undermining key livelihood activities such as rice farming and livestock grazing, with data from the Rwanda Agriculture and Animal Resources Development Board showing changes in agricultural output due to ecosystem stress (RAB, 2023). Population growth reported by the National Institute of Statistics of Rwanda is further intensifying land pressure, leading to encroachment and informal settlements in wetland areas (NISR, 2022).

Additionally, the loss of wetland area has reduced essential ecosystem services such as flood control and water regulation, as highlighted by the Rwanda Land Authority (NLA, 2023). Overall, these changes are weakening livelihoods, increasing risk exposure, and limiting sustainable development in the district.

Table 5: Summary of Key Socio-Ecological and Land Use Changes in Rugeramigozi Wetland (1993-2003-2013-2023)

Indicator	1993	2003	2013	2023	Change (1993-2023)	Data Source
Population (Shyogwe)	-	12738	44,771	50,966		NISR
Wetland area (ha)	111	90	62.1	14.5	-96.6ha	GIS LULC Analysis
Wetland cover (%)	62	50.2	34.6	8.1	-24%	LULC Classification
Agricultural land (ha)	45	65	89	135.5	+90ha	GIS Analysis
Agricultural land (%)	25.1	36.2	49.6	75.5	+50.4%	LULC Classification
Built-up area (ha)	5	7.6	13.7	18	+13ha	GIS Analysis
Built-up area (%)	2.8	4.2	76	10	4%	LULC Classification
Mean NDVI	0.62	0.55	0.48	0.40	Declining	Remote Sensing
Road length (km in buffer zone)	0.8	0.9	1.5	3	1.9km	GIS Digitization
Number of infrastructures	2-3	5	8	12-15	4 units	Field Survey/ GIS

NB: Analysis extract from NISR population statistics, GIS LULC classification and spatial analysis of Landsat imagery (1993–2023), NDVI Remote Sensing Outputs, and Field Survey Data.

Source: Author's compilation (2026).

The statistical evidence demonstrates that Wetland degradation in Rugeramigozi is not only an environmental transformation but also a socio-economic stressor. The combined LULC, NDVI, and socio-economic indicators show a consistent pattern where increased land conversion leads to ecological decline, reduced productivity, and heightened community vulnerability. These findings are consistent with regional studies in East Africa (Omagor and Barasa, 2018; Yasin, *et. al*., 2025), which report similar linkages between Wetland conversion, ecosystem degradation, and socio-economic impacts in rapidly developing peri-urban environments.

ISSN 2348-313X (Print)
International Journal of Life Sciences Research ISSN 2348-3148 (online)
Vol. 14, Issue 3, pp: (34-51), Month: July - September 2026, Available at: www.researchpublish.com

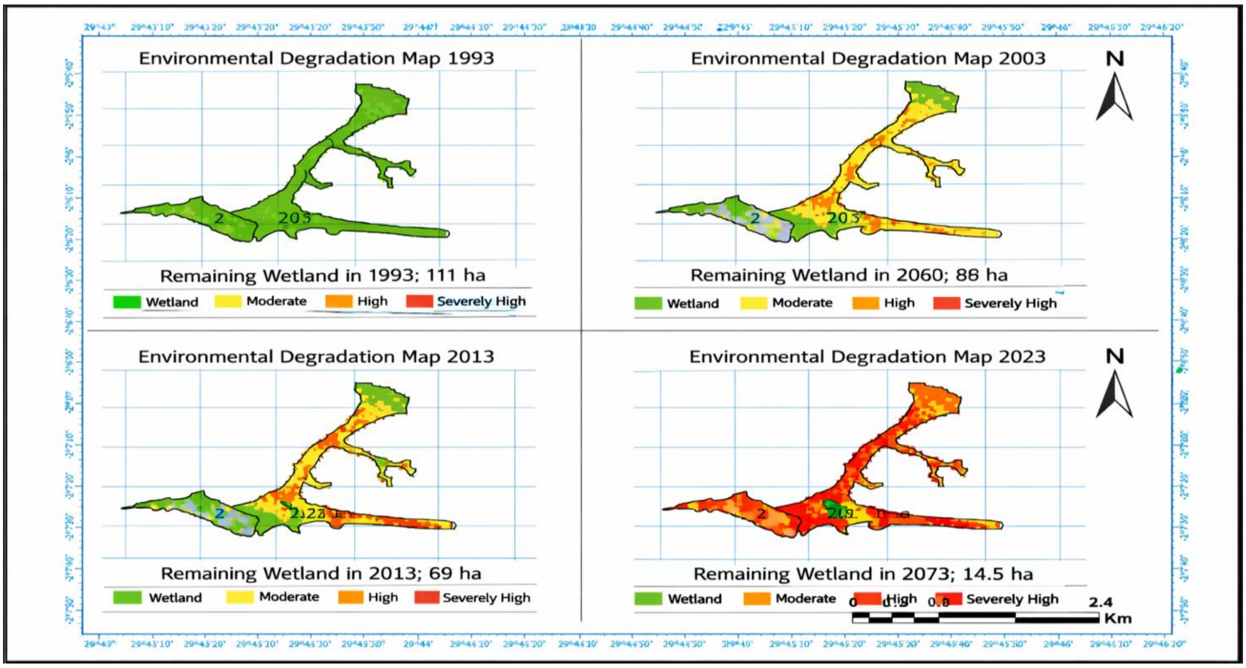

Figure 7: Environmental degradation Map of Lands Data (1993-2003-2013-2023)

Source: Author's compilation (2026)

3.3.2 Responses and Management Measures (Response -DPSIR)

3.3.2.1 Observed Responses

The study identified several responses implemented to address Wetland degradation in Rugeramigozi Wetland. These responses are mainly institutional, community-based, and planning-oriented:

- **Policy interventions on Wetland protection**: Government policies and regulations have been introduced to control Wetland encroachment and promote conservation. These include legal provisions restricting construction and agricultural activities within designated Wetland protection zones.
- **Local conservation initiatives:** Community-based organizations and local groups participate in Wetland protection through tree planting, environmental awareness campaigns, and small-scale restoration activities in degraded areas.
- **Land use planning and zoning:** Planning authorities have implemented zoning regulations and development control measures intended to guide settlement expansion and regulate land allocation within and around the Wetland system.

The DPSIR analysis indicates that current responses are largely fragmented, reactive, and insufficient to reverse ongoing Wetland degradation. Institutional coordination is weak, and enforcement of existing regulations is inconsistent. In addition, the absence of integrated and continuous monitoring systems such as GIS and remote sensing limits the ability of responsible authorities to detect and respond to land use changes in a timely manner.

As a result, implementation gaps persist, as evidenced by continued land conversion within the Wetland. Agricultural land has increased from 25% to 75% (approximately 45 ha to 135.5 ha), while built-up areas have expanded from 3% to 10% (approximately 5 ha to 18 ha). These trends suggest that existing response mechanisms have not effectively controlled anthropogenic pressure on the Wetland ecosystem.

Furthermore, most interventions are reactive rather than preventive, focusing on managing visible environmental impacts instead of addressing the underlying drivers such as population pressure, increasing demand for agricultural land, weak enforcement of environmental regulations, and limited integration of ecological considerations into land use planning. This limits the long-term sustainability of current conservation efforts.

Empirical evidence from LULC change detection and NDVI analysis supports these findings. The reduction in natural Wetland cover from 62% to 8.1% (approximately 111 ha to 14.5 ha, a loss of about 96.6 ha), together with the decline in hydrological features from 10% to 5% (approximately 18 ha to 9 ha), confirms continued ecological degradation despite existing interventions.

3.4 Results Discussion

The findings of this study reveal a substantial and progressive transformation of the Rugeramigozi Wetland ecosystem between 1993 and 2023. The analysis of Land Use and Land Cover (LULC) changes, NDVI trends, and spatial transition patterns demonstrates that the wetland has shifted from a predominantly natural ecological system into a highly human-modified landscape dominated by agricultural and built-up land uses. These findings confirm that anthropogenic activities, particularly agricultural expansion and urban growth, are the major drivers of Wetland conversion and environmental degradation in the study area. The results are consistent with broader regional and global patterns of Wetland degradation reported in Sub-Saharan Africa and other rapidly urbanizing regions.

(i) The LULC classification results indicate that natural Wetland vegetation declined dramatically over the study period. Wetland vegetation decreased from 61.8% in 1993 to only 8.1% in 2023, while agricultural land expanded from 25.1% to 75.5%. Built-up areas also increased from 2.8% to 10%, reflecting growing settlement and infrastructure development within and around the Wetland ecosystem.

(ii) Similarly, water bodies declined from 10.3% to 5.05%, indicating significant alteration of the hydrological system. These findings clearly demonstrate a continuous process of ecological transformation characterized by the replacement of natural Wetland ecosystems with human-dominated land uses. The observed decline in Wetland vegetation and water bodies has important ecological implications. Wetlands naturally function as ecological buffers that regulate hydrological processes, support biodiversity, recharge groundwater, and maintain water quality. However, the drastic reduction in Wetland extent and vegetation cover indicates that the ecological integrity of Rugeramigozi Wetland has been severely compromised. The fragmentation of Wetland vegetation observed in the classified maps further suggests declining habitat connectivity and increasing ecosystem instability. This pattern is consistent with the findings of Davidson (2014), who argued that Wetland degradation is largely associated with agricultural encroachment, hydrological modification, and increasing human pressure. Similarly, Millennium Ecosystem Assessment (2005) emphasized that Wetland degradation weakens ecosystem services such as flood regulation, carbon sequestration, and biodiversity conservation.

(iii) Agricultural expansion emerged as the dominant driver of Wetland conversion throughout the study period. The continuous increase in agricultural land from 25.1% in 1993 to 75.5% in 2023 demonstrates a strong dependence on Wetland-based cultivation. The conversion of Wetland areas into farmland is likely associated with population growth, increasing food demand, land scarcity, and local dependence on agriculture for livelihoods. This finding corresponds with studies conducted in East Africa by Beuel, *et. al.* (2016), Omagor and Barasa (2018), and Alemu, *et. al.* (2021), which identified agriculture as the leading driver of Wetland degradation in rapidly growing peri-urban regions. The results therefore confirm that Rugeramigozi Wetland follows a broader regional trend where fertile Wetland ecosystems are progressively converted into agricultural landscapes to support subsistence and commercial production.

(iv) The increase in built-up areas also demonstrates the growing influence of urbanization on Wetland transformation. Although the expansion of settlements and infrastructure was smaller compared to agricultural land, the growth rate was significant, increasing from 2.8% in 1993 to 10% in 2023. This reflects increasing settlement pressure associated with urban growth in Muhanga District. The development of roads, housing, and infrastructure within and around the Wetland contributes to land fragmentation, surface sealing, and permanent ecological alteration. The findings support the observations of Areo, *et. al.* (2024) and Seto, *et. al.* (2012), who emphasized that urban expansion significantly accelerates ecosystem degradation through land reclamation and infrastructure development.

(v) The NDVI analysis provided additional evidence of ecological degradation within the Wetland ecosystem. The study observed a continuous decline in vegetation health and biomass over time, with NDVI values progressively decreasing across the study period. High NDVI values recorded in earlier years represented dense and healthy Wetland vegetation, while lower NDVI values observed in later years reflected vegetation stress, ecosystem disturbance, and reduced ecological productivity. This trend confirms that land conversion processes have significantly weakened vegetation density and Wetland ecological condition. The findings correspond with studies by Orimoloye, *et.al.* (2020), Kaplan and Avdan (2017), and Berhanu, *et.al*. (2023), which demonstrated that declining NDVI values are strong indicators of Wetland degradation and increasing anthropogenic disturbance.

ISSN 2348-313X (Print)
International Journal of Life Sciences Research ISSN 2348-3148 (online)
Vol. 14, Issue 3, pp: (34-51), Month: July - September 2026, Available at: www.researchpublish.com

(vi) The statistical analysis further confirmed the relationship between land conversion and Wetland degradation. The Pearson correlation matrix showed a strong negative relationship between Wetland area and agricultural expansion (-0.95), as well as between Wetland area and built-up land (-0.92). In contrast, Wetland area showed a strong positive relationship with NDVI values (+0.89). These relationships indicate that increasing agricultural and settlement activities directly contribute to Wetland loss and declining vegetation condition. The findings therefore provide strong quantitative evidence that anthropogenic land use changes are closely associated with ecological degradation in Rugeramigozi Wetland.

(vii) The DPSIR framework showed that population growth, urbanization, and increasing food demand are the main drivers of environmental change in Rugeramigozi Wetland. These drivers have increased pressures such as agricultural encroachment, settlement expansion, and Wetland drainage, leading to reduced Wetland extent, declining vegetation cover, habitat fragmentation, and degraded hydrological conditions. Consequently, Wetland degradation has caused environmental and socio-economic impacts including increased flood risks, reduced water regulation capacity, biodiversity loss, and weakened community livelihoods. The study further revealed that Wetland degradation negatively affects communities dependent on Wetland resources for agriculture, grazing, and water supply, while increasing vulnerability to flooding and other environmental hazards.

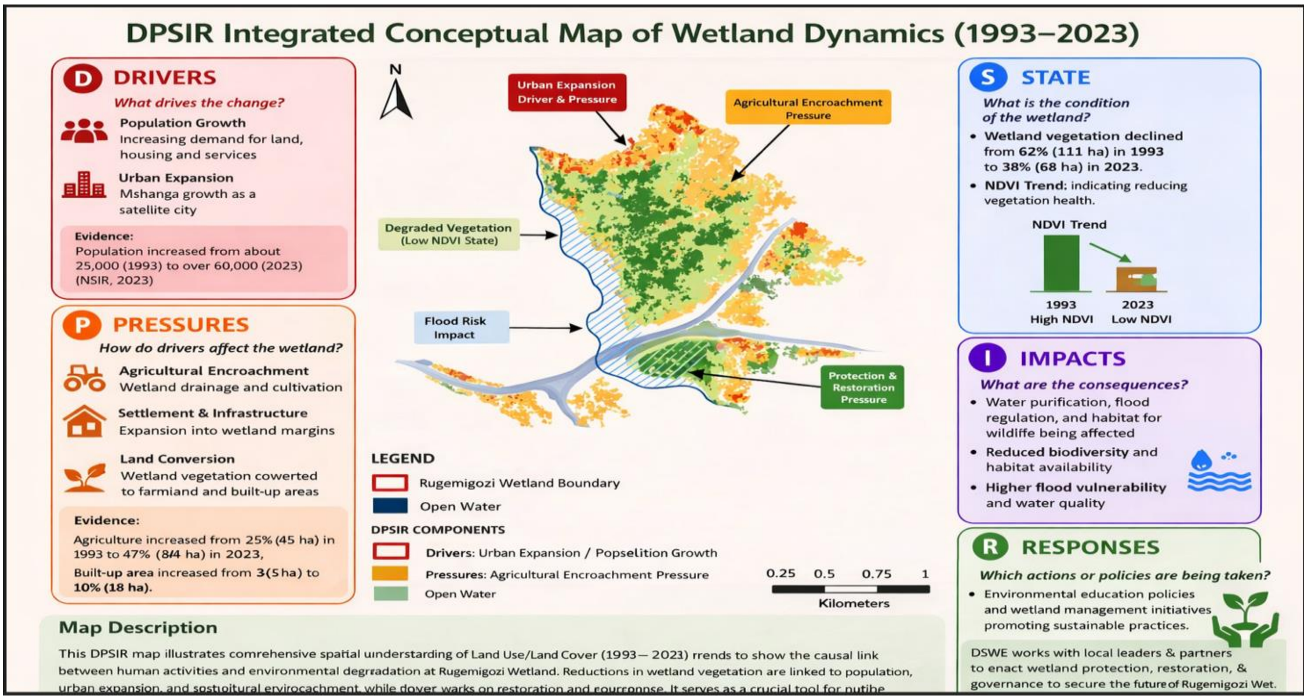

Figure 8: DPSIR Integrated Conceptual Map of Wetland Dynamics (1993-2003-2013-2023)

Source: Author's compilation (2026)

4. CONCLUSION

This study concludes that the Rugeramigozi Wetland underwent substantial degradation between 1993 and 2023**,** primarily as a result of human-induced land use and land cover (LULC) changes. The LULC analysis revealed a marked decline in wetland cover from 62% to 38%**,** representing a net loss of approximately 43 ha**,** accompanied by significant expansion of agricultural land and built-up areas. These changes demonstrate a progressive transition from a predominantly natural wetland ecosystem to a human-dominated landscape. Consistent with these findings, the Normalized Difference Vegetation Index (NDVI) analysis showed a decline in vegetation vigor and biomass, indicating reduced ecological integrity, ecosystem productivity, and resilience.

The DPSIR analysis further identified population growth, agricultural expansion, and urbanization as the principal drivers of wetland conversion, generating pressures that have altered ecosystem structure and function and diminished critical ecosystem services, including flood regulation, water retention, biodiversity conservation, and livelihood support. Although policy and institutional measures for wetland management exist, their effectiveness remains constrained by weak enforcement of environmental regulations, inadequate monitoring systems, and limited integration of Geographic Information Systems (GIS) and Remote Sensing technologies into routine wetland management. Overall, the findings demonstrate that without strengthened governance, continuous geospatial monitoring, and integrated land-use planning, the Rugeramigozi Wetland will remain vulnerable to further degradation, with significant implications for environmental sustainability, climate resilience, and sustainable development in Rwanda.

REFERENCES

[1] African Development Bank Group. (2024). Wetland ecosystem and climate adaptation assessment Impact assessment. AfDB. [Government/institutional document].

[2] Alemu, T., Nigussie, A., & Tadesse, M. (2021). Urban expansion and Wetland degradation in Ethiopian cities: Evidence from remote sensing analysis. Environmental Monitoring and Assessment, 193(11), 1–16. https://doi.org/10.1007/s10661-021-0943-2

[3] Amler, B., Betke, M., Eger, H., Ehrich, C., Kohler, A., Kutter, A., & von Lossau, A. (2016). *Sustainable land management in practice: Guidelines and best practices for sub-Saharan Africa*. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ).

[4] Andreasen, M. H., Agergaard, J., Kofie, R. Y., Møller-Jensen, L., & Oteng-Ababio, M. (2022). Urban conversion in ecologically sensitive areas: Drivers, impediments and consequences. Buildings and Cities, 3(1), 920–938. https://doi.org/10.5334/bc.210

[5] ARCOS. (2019). Rwanda Wetlands ecological integrity rapid assessment report. Albertine Rift Conservation Society.

[6] Areo, I. O., & Ishaya, S. (2018). Assessment of land use/land cover change in Kwali Area Council using geo-informatic techniques. The Environmental Studies, 1(2), 38–47.

[7] Berhanu, B., Seleshi, Y., & Melesse, A. M. (2023). Application of NDVI for vegetation monitoring and land degradation assessment. *Remote Sensing Applications: Society and Environment, 30*, 100936.

[8] Campbell, J. B., & Wynne, R. H. (2011). Introduction to remote sensing (5th ed.). Guilford Press.

[9] Chowdhury, S., Khare, D., & Aggarwal, S. P. (2025). Application of the DPSIR framework for assessing land use change impacts on Wetland ecosystems. Environmental Monitoring and Assessment, 197(2), 112–126.

[10] Congalton, R. G., & Green, K. (2019). Assessing the accuracy of remotely sensed data: Principles and practices (3rd ed.). CRC Press.

[11] Convention on Wetlands. (2025). Global Wetland Outlook 2025: Valuing, conserving, restoring and financing Wetlands. Ramsar Convention. [Report].

[12] Darkwah, R. M., Cobbinah, P. B., & Anokye, P. A. (2018). Contextualising urban resilience in Ghana: Local perspectives and experiences. Geoforum, 94, 12–23. https://doi.org/10.1016/j.geoforum.2018.05.023

[13] Darrah, S. E., Shennan-Farpón, Y., Loh, J., Davidson, N. C., Finlayson, C. M., Gardner, R. C., & Walpole, M. J. (2019). Improvements to the Wetland Extent Trends (WET) index as a tool for monitoring natural and human-made Wetlands. Ecological Indicators, 99, 294–298.

[14] Davidson, N. C., Fluet Chouinard, E., & Finlayson, C. M. (2018). Global extent and distribution of Wetlands: Trends and issues. Marine and Freshwater Research, 69(4), 620–627. https://doi.org/10.1071/MF17019

[15] Folke, C., Carpenter, S. R., Walker, B., Scheffer, M., Chapin, T., & Rockström, J. (2010). Resilience thinking: Integrating resilience, adaptability and transformability. Ecology and Society, 15(4), 20. https://doi.org/10.5751/ES-03610-150420

[16] Garba, S. I., Ebmeier, S. K., Bastin, J. F., Mollicone, D., & Holden, J. (2025). Wetland fragmentation associated with large populations across Africa. Nature Communications, 16, Article 5065. https://doi.org/10.1038/s41467-025-59373-2

[17] Gumma, M. K., Thenkabail, P. S., Teluguntla, P. G., Oliphant, A., Xiong, J., Giri, C., Pyla, V., & Dixit, S. (2020). Agricultural cropland extent and areas of South Asia derived using Landsat satellite 30-m time-series big data using random forest machine learning algorithms. GIScience & Remote Sensing, 57(6), 789–808. https://doi.org/10.1080/15481603.2020.1751560

[18] Hiraga, M., Sato, Y., & Nakamura, T. (2021). Hydrological impacts of land use change on wetland ecosystems. *Hydrological Sciences Journal, 66*(5), 789–803.

[19] Intergovernmental Panel on Climate Change. (2023). Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (AR6 SYR). IPCC. https://www.ipcc.ch/report/ar6/syr/

[20] Institute of Policy Analysis and Research (IPAR). (2023). Rwanda environmental policy 2023. IPAR Rwanda

[21] Kaplan, G., & Avdan, U. (2017). Object-based water body extraction model using Sentinel-satellite imagery. *European Journal of Remote Sensing, 50*(1), 137–143.

[22] Kundu, S., Chakraborty, A., & Patel, P. P. (2024). Wetland degradation and its implications for livelihoods, ecosystem services, and the Sustainable Development Goals: A global synthesis. Sustainable Production and Consumption, 41, 217–232

[23] Kristensen, P. (2004). The DPSIR framework. European Environment Agency.

[24] Lambin, E. F., Turner, B. L., Geist, H. J., Agbola, S. B., Angelsen, A., Bruce, J. W., … Xu, J. (2001). The causes of land-use and land-cover change: Moving beyond the myths. Global Environmental Change, 11(4), 261–269. https://doi.org/10.1016/S0959-3780(01)00007-3

[25] Li, X., Zhou, Y., & Asrar, G. R. (2017). Urbanization and its impacts on ecosystem services and vegetation dynamics. *Landscape and Urban Planning, 162*, 68–77.

[26] Liu, J., Dietz, T., Carpenter, S. R., Alberti, M., Folke, C., Moran, E., … Taylor, W. W. (2007). Complexity of coupled human and natural systems. Science, 317(5844), 1513–1516. https://doi.org/10.1126/science.1144004

[27] Lu, D., Mausel, P., Brondízio, E., & Moran, E. (2004). Change detection techniques. International Journal of Remote Sensing, 25(12), 2365–2401. https://doi.org/10.1080/0143116031000101675

[28] Millennium Ecosystem Assessment (MEA). (2005). Ecosystems and human well-being: Wetlands and water synthesis. World Resources Institute.

[29] Ministry of Agriculture and Animal Resources. (2023). MINAGRI annual report 2023/24 [Government report]. Ministry of Agriculture and Animal Resources.

[30] Mitsch, W. J., & Gosselink, J. G. (2015). Ecosystem services of Wetlands (5th ed.). John Wiley & Sons.

[31] Moisa, M. B., Tadesse, T., & Tesfaye, S. (2023). Land use/land cover dynamics using GIS and remote sensing in East Africa. *Environmental Monitoring and Assessment, 195*, 123

[32] Nabahungu, N. L. (2012). Problems and opportunities of wetland management in Rwanda. *Agricultural Water Management, 106*, 1–9.

[33] National Institute of Statistics of Rwanda (NISR). (2025). *Statistical yearbook*. Government of Rwanda.

[34] Nile Basin Initiative (NBI). (2022). Rwanda Wetlands governance and management profile (NBI Technical Report WRM/WBS-2022-12).

[35] Oduro, W., Mensah, E., & Boateng, K. (2024). Ecosystem service loss due to wetland degradation in Africa. *Ecosystem Services, 65*, 101550.

[36] OECD. (1993). OECD core set of indicators for environmental performance reviews. Organisation for Economic Co-operation and Development.

[37] Omagor, J. G. (2018). Effect of human Wetland conversion on the degradation of Lubigi Wetland System, Kampala City (Master's dissertation, Makerere University, College of Agricultural and Environmental Sciences). Makerere University Repository. https://dissertations.mak.ac.ug/handle/20.500.12281/5248

[38] Orimoloye, I. R., Kalumba, A. M., & Mazinyo, S. P. (2020). Monitoring vegetation dynamics using NDVI. *Environmental Monitoring and Assessment, 192*, 1–14.

[39] Ozesmi, S. L., & Bauer, M. E. (2002). Satellite remote sensing of wetlands. *Wetlands Ecology and Management, 10*(5), 381–402.

[40] Pettorelli, N., Vik, J. O., Mysterud, A., Gaillard, J. M., Tucker, C. J., & Stenseth, N. C. (2005). Using the satellite-derived NDVI to assess ecological responses to environmental change. Trends in Ecology & Evolution, 20(9), 503–510. https://doi.org/10.1016/j.tree.2005.05.011

[41] Ramsar Convention Secretariat. (2018). Global Wetland outlook: State of the world's Wetlands. and their services to people. Ramsar Convention Secretariat.

[42] Rebelo, L. M., Finlayson, C. M., & Nagabhatla, N. (2010). Remote sensing and GIS forl Wetland inventory, mapping and change analysis. Journal of Environmental Management, 91(11), 2144–2153.

[43] Rwanda Green Fund. (2025). Rwanda Green Fund annual activity report 2023–2024 [Annual report]. Rwanda Green Fund.

[44] Seto, K. C., Güneralp, B., & Hutyra, L. R. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. Proceedings of the National Academy of Sciences, 109(40), 16083–16088. https://doi.org/10.1073/pnas.1211658109

[45] Turner, B. L., Verburg, P. H., & Lambin, E. F. (2016). Land system science and sustainable development of the Earth system. Annual Review of Environment and Resources, 41, 451–478.

[46] UNEP. (2013). *Using the DPSIR framework for environmental reporting*. United Nations Environment Programme.

[47] United Nations Environment Programme. (2024). Wetlands: an important tool to build resilience (Inger Andersen address). UNEP. https://www.unep.org/news-and-stories/speech/Wetlands-important-tool-build-resilience

[48] Uwizeyimana, J., Kashirande, H., Ukwishaka, D., Nshimiyimana, A., Mwizerwa, F., Hategekimana, G., Ndagijimana, S. M. A., Nsengiyumva, C., & Rwabuhungu, D. E. (2022). Wetland restoration and farming practices prohibition towards local users' livelihood insights of Rugezi Wetland, Rwanda. International Journal of Innovative Science and Research Technology, 7(9), 1160–1169.

[49] World Food Programme. (2024). Wetlands contributions to food security and resilience Policy report. WFP.

[50] Wilson, E. H., & Norman, L. M. (2018). Remote sensing of wetland vegetation. *Remote Sensing, 10*(2), 1–20.

[51] Xu, H., Wang, Y., & Guan, H. (2019). NDVI-based ecological assessment of vegetation health. *Ecological Indicators, 98*, 103–113.

[52] Yasin, H., Mohammed, A., & Abebe, G. (2025). Land use–land cover dynamics in Wetlands using remote sensing and GIS: Evidence from Ethiopia. African Geographical Review.

[53] Zedler, J. B., & Kercher, S. (2005). Wetland resources: Status, trends, ecosystem services, and restorability. Annual Review of Environment and Resources, 30, 39–74.

[54] Zhang, Y., Liu, Y., & Wu, J. (2023). Urbanization and wetland loss: A global perspective. *Science of the Total Environment, 857*, 159–172.