IMPACT OF ANTHROPOGENIC ACTIVITIES ON WATER QUALITY IN RUGERAMIGOZI WETLAND, RWANDA

NIYONSENGA Leonce[1]
Dr. NSANZUMUKIZA Martin Vincent[2]
NTAHONDEREYE Aminadab[3]
MUKARUGORI Christine[4]
Jovine NSEKANABANGA[5]

[1]Master of Science in Environmental and Development Studies, with a Specialization in Environmental Economics and Natural Resource Management at University of Lay Adventists of Kigali (UNILAK). Community Development and Outreach Officer at the Albertine Rift Conservation Society (ARCOS Network).
[2]Expert in Environmental Assessment, PhD in environmental engineering from the University of the Chinese Academy of Sciences in affiliation with the Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences (2014–2018). Director of Research and Consultancy at the University of Lay Adventists of Kigali (UNILAK).
[3]Lecturer at the University of Lay Adventists of Kigali (UNILAK).
[4]Having satisfied the requirements for the award of Bachelor of science (Hons) (Crop Production) at the University of Rwanda, College of Agriculture, Animal Science and Veterinary Medicine (2013-2017). Coffee Washing Station Manager at the Nyamulinda Coffee Growers Ltd.
[5]Bachelor's degree in Applied Statistics from the University of Rwanda and an MBA in Project Management from UNILAK, Statistician and Energy Analyst at Rwanda Energy Group (REG/EDCL). 12 years of experience in energy systems modeling and sustainable energy planning, supporting clean energy solutions that promote environmental sustainability.

Abstract:* *Anthropogenic activities increasingly threaten wetland water quality, with ecological and socio-economic implications in Rwanda. The Rugeramigozi Wetland in Muhanga District, a critical agricultural and ecological resource, has experienced intensive farming, urbanization, waste disposal, and resource extraction. This study assessed the impact of these human activities on water quality, focusing on physical (turbidity, pH, electrical conductivity), chemical (total nitrogen, total phosphorus, chemical oxygen demand), parameters, while also examining local perceptions and policy effectiveness. A mixed-methods approach was employed: primary data was collected through structured questionnaires administered to 133 farmers, residents, and 18 institutional officers, supplemented by focus group discussions with environmental and agricultural officials to make 151 total respondents (133 attended closed ended questions and 18 attended focus group discussion); secondary data were obtained from reports and institutional records. Water samples from five strategic sites were analyzed in the laboratory following standardized procedures (Primary data). Results showed that anthropogenic activities significantly influenced water quality (Pearson correlation $r = 0.549$, $p < 0.01$), with agricultural intensity, solid waste disposal, sanitation practices, and resource exploitation strongly associated with physical and chemical degradation. Laboratory analysis indicated elevated turbidity, chemical oxygen demand, and nutrient concentrations in areas adjacent to agriculture, urban settlements, and waste disposal zones, confirming local perceptions of declining water clarity, color, and odor. Community awareness of wetland protection laws and participation in monitoring programs were moderate, indicating gaps in enforcement and engagement. The study concludes that human activities are major drivers of water quality changes in Rugeramigozi Wetland and recommends strengthening policy enforcement, promoting sustainable agricultural and sanitation practices, and enhancing community participation. Findings provide actionable insights for policymakers, environmental managers, and local communities to protect wetland ecosystems while sustaining livelihoods and biodiversity.*

***Keywords:* Agricultural pollution; Anthropogenic activities; Rugeramigozi Wetland, Water quality and Wetlands**

0. Introduction

Globally, the degradation of water quality resulting from anthropogenic activities has emerged as one of the most pressing environmental issues of the 21st century. The accelerated pace of industrialization, urbanization, and population growth has increased the release of pollutants into aquatic ecosystems, threatening water availability and ecosystem integrity (UNEP, 2023). Human-induced pollution introduces nutrients, heavy metals, sediments, and pathogens that alter the chemical, physical, and biological characteristics of water bodies. According to the Food and Agriculture Organization (FAO, 2024), approximately 80% of global wastewater is discharged untreated into the environment, leading to the contamination of rivers, lakes, and wetlands. Wetlands are highly vulnerable because they act as natural filters and carbon sinks, yet they receive high pollutant loads from agricultural and industrial sources (Ishimwe, 2023). As a result, the global decline in water quality is increasingly linked to anthropogenic pressures, with implications for human health, biodiversity, and sustainable development.

At the regional level, Sub-Saharan Africa faces a growing challenge in balancing socioeconomic development with the preservation of aquatic ecosystems. Wetlands in this region are often reclaimed for agricultural production to meet food security needs, especially for rice and vegetable cultivation (FES, 2020). However, these practices frequently occur without adequate environmental controls, resulting in nutrient overloading, eutrophication, and the degradation of natural filtration systems. The lack of wastewater treatment infrastructure and insufficient environmental regulation exacerbate water contamination, especially around urban centers and intensive farming zones (World Bank, 2022). In East African countries such as Uganda, Kenya, and Tanzania, studies have revealed that runoff from farms and the discharge of untreated domestic effluents lead to elevated levels of TN, TP, and heavy metals in wetlands (Sekomo, B. et al., 2025). Consequently, the regional water quality decline not only threatens aquatic ecosystems but also affects community livelihoods dependent on wetland resources for farming, fishing, and livestock rearing.

Nationally, Rwanda's wetlands play an essential role in supporting livelihoods, maintaining biodiversity, and providing ecosystem services such as flood regulation and water purification. Covering over 278,000 hectares, wetlands account for about 10% of the country's total land area and are vital for agriculture, especially rice cultivation and horticulture (REMA, 2021). However, increasing anthropogenic pressures driven by rapid population growth, expansion of agricultural land, and urban encroachment have significantly altered wetland ecosystems (Nsengiyumva, 2021). The misuse of agrochemicals, poor waste disposal practices, and inadequate sanitation infrastructure have contributed to the deterioration of water quality in these areas. Elevated concentrations of nutrients, pesticides, and heavy metals have been reported in several Rwandan wetlands, leading to eutrophication, reduced dissolved oxygen, and contamination of irrigation water. These changes not only compromise ecological balance but also have implications for agricultural productivity and public health (Habimana, 2024).

Specifically, the Rugeramigozi Wetland in Rwanda's Southern Province exemplifies these challenges. The wetland has experienced increasing agricultural intensification and human settlement, leading to the direct discharge of household wastewater and agricultural runoff into the wetland ecosystem. The use of fertilizers and pesticides, combined with poor waste management, has heightened the risk of contamination through nutrient loading and chemical accumulation (Ndayisaba, 2022). Despite its ecological and socioeconomic importance, there remains limited empirical data on the extent and impact of these anthropogenic activities on the wetland's water quality. Key parameters such as turbidity, electrical conductivity, pH, nitrate and phosphate concentrations, and heavy metal content remain under-investigated. Understanding these parameters is critical for assessing ecosystem health and ensuring the sustainability of agricultural productivity in the region (Bazambanza, 2024).

Therefore, this study seeks to evaluate the impact of anthropogenic activities on water quality in the Rugeramigozi Wetland, with a particular focus on agricultural and domestic influences. It further aims to assess how policy frameworks such as the National Irrigation Policy and Wetlands Protection Guidelines moderate these impacts. By integrating scientific evidence and policy analysis, the research contributes to the design of effective management strategies for sustaining wetland ecosystems and promoting environmentally sound agricultural development in Rwanda.

1. Problem Statement

Globally and regionally, wetlands are increasingly degraded by anthropogenic activities such as agriculture, urbanization, and industrial development, which negatively affect water quality and ecosystem health (Ishimwe, 2023). Excessive use of fertilizers and pesticides introduces high levels of nutrients, particularly TN and TP, causing eutrophication and ecological imbalance (FAO, 2024). In East Africa and Sub-Saharan Africa, agricultural runoff, untreated wastewater, weak policy enforcement, and inadequate waste management have led to increased turbidity, chemical contamination, and declining wetland functions (Nyenje, 2021). Although integrated water resource management and sustainable land-use practices are widely recommended, implementation remains limited (UNEP, 2023).

In Rwanda, wetlands play a vital role in agriculture and livelihoods but are under growing pressure from poor waste disposal, excessive agrochemical use, and urban encroachment (Sekomo, B. et al., 2025). Studies have reported elevated nutrient and pollutant levels in several wetlands; however, specific empirical data on Rugeramigozi Wetland are scarce (FES, 2020). The lack of localized evidence limits effective management and policy evaluation. This study therefore aims to assess the impact of anthropogenic activities on water quality in Rugeramigozi Wetland to support sustainable wetland management and environmental protection (Ndayisaba, 2022).

2. Empirical Review

In the study by Katusiime and Barakagira (2025) which investigated the impact of agricultural practices on the water quality of Rwakaiha Wetland in Kyegegwa District, Uganda, the objective was to document the agricultural practices around the wetland and to measure physicochemical water parameters to see the influence of those practices. They used a combination of questionnaire surveys to characterize farming practices (crops, animal rearing, aquaculture) together with in situ and laboratory experiments to measure parameters such as COD, pH, BOD, EC, turbidity, and TDS. The findings showed that agricultural practices including crop growing, animal rearing, and aquaculture were prevalent, and that while most parameters were within WHO permissible limits, COD was elevated suggesting organic pollution. This illustrates that even in agricultural contexts where many measures appear acceptable, specific indicators may reveal significant stress. However, the study did not address parameters, nor did it distinguish spatially among different intensity levels of agriculture (e.g. small vs large farms) or consider seasonal variation explicitly, leaving a gap in understanding how those dimensions affect wetland health (Katusiime, 2025).

In Umwali et al. (2021) studying Lake Muhazi in Rwanda, the objective was to examine how land use and land cover (LULC) influence the Spatio-seasonal variation of water quality. They measured multiple physical and chemical water parameters across seasons and in different zones around the lake, comparing areas under forest, agriculture, settlements etc. They found that water quality varied significantly with land use: areas near agriculture and human settlements showed higher nutrient loads, higher turbidity, and lower clarity particularly during rainy season, whereas forested zones maintained better quality. This demonstrates how changes in land cover can modulate pollution and runoff. The gap is that the work is on a lake rather than a wetland proper, and there is limited information on microbial or contamination or how local practices (e.g. fertilizer application, waste disposal) specifically contribute to the measured differences (Umwali, 2021).

In Sanusi, Olutona, Wawata et al. (2024) in Kampala and Mbarara Districts, Uganda, their objective was to assess groundwater and surface water quality under anthropogenic pressures using a water quality index and multivariate statistics. They collected monthly water samples over a year, measured about ten physicochemical parameters including pH, temperature, chloride, sulphate, nitrate, EC, TDS, TSS, total solids, phosphate, and then applied statistical analyses to discern pollution sources and water suitability. The findings indicated significant variation in quality, with some sites exceeding acceptable limits especially for TSS, TDS and certain nutrients, showing that anthropogenic activities (urban runoff, agricultural inputs) are playing a major role. However, gaps include that this was not specifically focused on wetlands; the study does not examine parameters or the effect of solid waste or sanitation infrastructure directly, nor does it link specific anthropogenic activities in fine spatial detail to particular pollutant levels (Sanusi, 2024).

The work "Analysis of decomposition in degraded vs semi-intact urban wetlands" by Kibira, Aremu, Masaba et al. (2023) in Uganda had the objective of comparing ecological health (via decomposition rates) of wetlands under different disturbance levels, while also exploring how physicochemical parameters correspond. Using litter bag decomposition with Pennisetum purpureum, measuring parameters such as pH, temperature, TDS, dissolved oxygen, conductivity, and applying exponential decay models and correlation tests, they found that degraded wetlands have considerably faster decomposition rates; decomposition correlated positively with temperature, conductivity, pH and negatively with TDS and dissolved oxygen. This shows how anthropogenic disturbance alters physical conditions, accelerating processes like organic matter breakdown, which can stress wetland ecological functions. Yet the study did not explicitly include water quality thresholds relative to human health, nor did it incorporate microbial risk; also, the identified disturbances are general ("degraded") rather than specified by activity (industry, settlement density, etc.), so linking specific anthropogenic sources to observed changes remains underdeveloped (Kibira, 2023).

In Tenywa, Omara, Kwikiriza, Angiro & Ntambi (2024) investigating spring water quality in a flood-prone area of Kampala, Uganda, their objective was to understand sanitary and limnochemical (chemical + physical) conditions of springs, particularly in relation to flooding and contamination. They collected samples and measured indicators including physical parameters, chemical (nutrients, pH etc.), and sanitary indicators, to see how flood events influence contamination. They found that during flood events, springs exhibit elevated levels of certain chemical pollutants and sanitary risk, indicating that flooding exacerbates pollution transfer from informal settlements or runoff. Nevertheless, the research was not centered on wetland systems per se, but on springs; detail was present but perhaps not as spatially detailed in terms of particular anthropogenic sources, and the study duration was relatively short, limiting understanding of seasonal cycles beyond immediate flood events (Tenywa, 2024).

The study "Assessing Wetland Health Through Decomposition in Degraded and Semi-Intact Wetlands in Uganda" (same by Kibira et al.) has already been touched, but notably its methodology of applying litter decomposition experiments plus measurement of physicochemical parameters provides strong evidence of how ecological function declines with disturbance. That said, the gap remains that it does not include analysis of chemical parameters such as specific nutrient species across seasons, nor microbiological contamination or policy/regulation or community action as modifiers of the health (Kibira, 2023).

A study on detecting wetland encroachment and urban agriculture in Kampala and Wakiso by remote sensing (Detecting wetland encroachment and urban agriculture land classification in Uganda) aimed to quantify how much wetland area has been lost over 30 years in those cities, and map where agriculture has expanded into wetland zones using hyper-temporal satellite imagery. They found substantial conversion of wetland land to built-up areas and crop agriculture, giving spatial detail of where wetland encroachment is occurring. This illustrates clearly the link between anthropogenic land use change and wetland loss, but does not measure water quality directly (physicochemical,) in the affected ground or water bodies, leaving a gap in connecting land cover change with water quality metrics (Twesigye, 2025).

Finally, the Rwandan study "Impact analysis of constructed wetland for wastewater management in Rwanda" (2025) sought to measure the effectiveness of a constructed wetland in Kigali (Gasabo district) by measuring eight physicochemical parameters in influent and effluent over both dry and rainy seasons, computing removal efficiencies and comparing to WHO standards and Water Quality Index measures. They found elevated pollution in the influent, good removal efficiency (between 16-80%), and that effluence met quality standards, showing that constructed wetlands are promising mitigation tools. However, it did not include parameters, nor does it assess how local anthropogenic activities upstream affect influent load in specific detail (which activities contribute what pollutants) or examine policy or community practices influencing pollutant loads (Mutoni, 2025).

3. Conceptual framework of the study

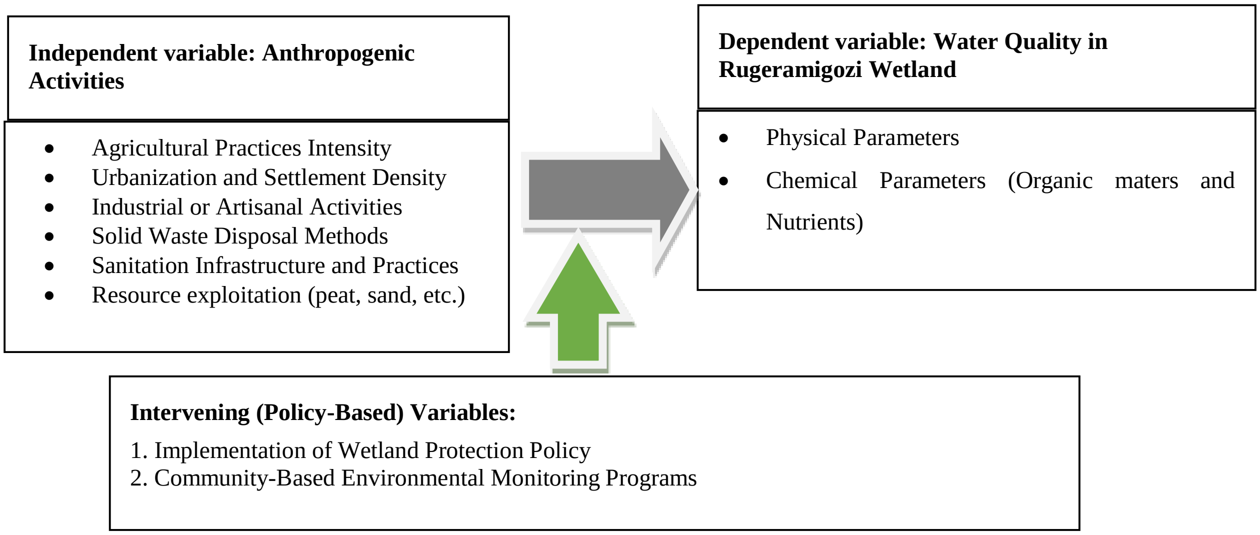
The relationship between anthropogenic activities and water quality in Rugeramigozi Wetland is shaped by a complex interaction of environmental pressures and regulatory controls. Key anthropogenic activities including the intensity of agricultural practices, use of fertilizers and pesticides, urban settlement density, industrial or artisanal operations, solid waste disposal methods, and sanitation infrastructure serve as primary drivers of pollution within the wetland ecosystem.

These human-induced pressures lead to the alteration of critical water quality indicators such as pH levels, turbidity, Biological Oxygen Demand (BOD), nitrate and phosphate concentrations,

. For instance, excessive agrochemical use may elevate nitrate and phosphate levels, leading to eutrophication, while poor sanitation and unregulated waste disposal contribute to increased BOD, signaling fecal contamination and organic pollution. Likewise, urban sprawl and artisanal activities introduce solid and chemical pollutants that affect water clarity and acidity. However, the degree to which these impacts manifest is influenced by the presence and effectiveness of policy-based intervening variables.

The implementation of wetland protection laws such as Law N° 48/2018 on Environment and the operation of Community-based environmental monitoring programs can mitigate the adverse effects of human activities by enforcing compliance, promoting awareness, and fostering local stewardship. These policies act as filters, either amplifying or weakening the link between human activity and water degradation, depending on their enforcement level and community engagement. Thus, this study conceptualizes water quality as the dependent outcome of anthropogenic stressors moderated by institutional and policy interventions.

Figure 1: Conceptual Framework of the Study



Source: Author, (2025)

4. Study Methodology

This section gives in details methods and techniques which are used to achieve study objectives and testing validity of the study objectives and hypotheses. It shows study design, population and sample size, sampling techniques, data collection tools, methods for data processing and data analysis. Here below are details:

4.1 Study objective

To assess the impact of anthropogenic activities on water quality in Rugeramigozi Wetland and evaluate how policy interventions influence this relationship. Specifically, this study intends to achieve the following objectives:

To assess the main anthropogenic activities affecting Rugeramigozi Wetland.

To determine water quality of Rugeramigozi Wetland

To analyze the relationship between identified anthropogenic activities and changes in water quality of Rugeramigozi Wetland.

4.2 Study Hypotheses

The above research objectives are based on the following first assumptions (hypotheses):

H_{01}: Anthropogenic activities have no significant effect on the physical parameters of water quality in Rugeramigozi Wetland.

H_{02}: Anthropogenic activities have no significant effect on the chemical parameters (organic matter and nutrients) of water quality in Rugeramigozi Wetland.

4.3 Summary of Methodology

The study was conducted in Rugeramigozi Wetland located in Muhanga District, Southern Province of Rwanda, covering about 472.24 hectares and fed by the Rugeramigozi Dam. The wetland is an intensively used agricultural ecosystem where farming activities such as maize, beans, vegetables, and rice cultivation are practiced. The area has experienced significant land-use changes over time due to increased agricultural expansion and settlement, making it suitable for examining how human activities influence water quality. It lies within a densely populated district where most households depend on agriculture and livestock farming, increasing pressure on wetland resources.

The research adopted a descriptive, correlational, and experimental design. The descriptive aspect was used to document existing conditions in the wetland, the correlational component examined relationships between human activities and water quality, while the experimental aspect involved laboratory testing of water samples collected from different land-use zones. Both primary data (from questionnaires administered to farmers, residents, and officials) and secondary data (from institutional reports and environmental agencies such as REMA and RWB) were used. Water samples were collected from multiple points including agricultural, urban, industrial, waste-affected, and riverine zones and analyzed for physical and chemical parameters using standard laboratory methods such as pH measurement, turbidity analysis, conductivity testing, spectrophotometry, and membrane filtration.

The study population consisted of 218 individuals, including 200 local farmers and residents, 10 environmental and agricultural officers, and 8 local leaders and community committee members. From this population, a sample size of 151 respondents was selected using Slovin's formula. Stratified sampling was used for community members based on their location and activities, while purposive sampling was applied to key institutional respondents. Water sampling followed a systematic spatial approach, where samples were taken from upstream, midstream, downstream, and areas influenced by different human activities to capture variations in water quality.

Data was collected using structured questionnaires and documentary review. The questionnaires captured information on agricultural practices, urbanization, waste management, sanitation, and resource exploitation, as well as perceptions of changes in water quality. Secondary data was obtained from institutional reports and previous studies. Laboratory analysis categorized water quality into physical and chemical parameters, all tested using standardized procedures under controlled conditions to ensure accuracy and reliability.

Data processing involved editing, coding, and tabulation to ensure completeness and consistency. Quantitative data were analyzed using SPSS, where descriptive statistics such as means, percentages, and standard deviations were used, while correlation and multiple regression analyses were applied to examine the relationship between anthropogenic activities and water quality. Qualitative data were analyzed using thematic content analysis to identify key patterns in perceptions and institutional responses. A regression model was used to determine the combined influence of agricultural practices, urbanization, industrial activities, waste disposal, sanitation, and resource extraction on water quality.

Validity was ensured through expert review and alignment with established environmental standards, while reliability was strengthened through pre-testing of instruments, standardized procedures, and the use of accredited laboratory methods. The study also considered ethical principles, including informed consent, confidentiality, voluntary participation, and institutional authorization from relevant authorities, ensuring that all data collection and reporting processes complied with academic and professional research ethics.

5. Findings

This presents the socio-economic characteristics of respondents in relation to their interaction with Rugeramigozi Wetland. These characteristics are important for understanding how demographic and socio-economic factors influence human activities that affect wetland water quality. The results show that most respondents are male, within the economically active age group, and have lived in the area for more than a decade, indicating long-term engagement with wetland-related livelihoods such as agriculture and settlement. In addition, the majority are married and have attained primary-level education, suggesting that household decision-making processes and relatively low levels of formal environmental education may significantly shape land use practices, sanitation behavior, and resource utilization that contribute to wetland degradation.

5.1 Socio-Economic Characteristics of Respondents

The demographic characteristics of respondents are closely linked to the study's focus on anthropogenic impacts on Rugeramigozi Wetland. The majority are male (62.4%), within the economically active age group (25–45 years), and have lived or worked in the area for over 10 years (78.2%), indicating long-term involvement in activities such as agriculture, settlement, and resource use that affect water quality. Most respondents are married (77.4%) and have primary-level education (56.4%), suggesting that household decision-making and limited formal environmental education may influence land use, sanitation, and waste management practices contributing to wetland degradation.

5.1 Main anthropogenic activities affecting Rugeramigozi Wetland

The Rugeramigozi Wetland is affected by multiple interconnected human activities that significantly degrade its ecological integrity and water quality. Survey results consistently show very high levels of agreement (mean scores mostly above 4.0 on a 5-point scale) that agriculture, settlement expansion, industrial activities, waste disposal, poor sanitation, and resource extraction are the key drivers of wetland degradation. Across all indicators, respondents expressed strong consensus, with most variables showing more than 60%–80% combined agreement and strong agreement.

5.1.1 Agricultural Practices Intensity

Agricultural activities are a major pressure on the wetland. All respondents agreed that chemical fertilizer and pesticide use has increased, with 74 (55.6%) agreeing and 59 (44.4%) strongly agreeing (mean = 4.44, SD = 0.499). Similarly, 88 (66.2%) agreed and 45 (33.8%) strongly agreed that farmland runoff enters the wetland during rainfall (mean = 4.34, SD = 0.475). Over-cultivation near the wetland was also widely acknowledged by 83 (62.4%) agreeing and 40 (30.1%) strongly agreeing (mean = 4.23, SD = 0.572). The strongest concern was the lack of soil and water conservation practices, with 25 (18.8%) agreeing and 108 (81.2%) strongly agreeing (mean = 4.81, SD = 0.392). Overall, these findings confirm that intensified agriculture is a major contributor to wetland degradation.

5.1.2 Urbanization and Settlement Density

Urban expansion and population growth are also strongly linked to wetland stress. Expansion of settlements by reducing vegetation was supported by 59 (44.4%) agreeing and 64 (48.1%) strongly agreeing (mean = 4.41, SD = 0.628). Untreated domestic wastewater discharge showed high agreement, with 49 (36.8%) agreeing and 79 (59.4%) strongly agreeing (mean = 4.56, SD = 0.570). Increased population pressure on wetland resources was confirmed by 30 (22.6%) agreeing and 88 (66.2%) strongly agreeing (mean = 4.47, SD

= 0.884). Additionally, 50 (37.6%) agreed and 65 (48.9%) strongly agreed that urban growth has altered drainage patterns (mean = 4.32, SD = 0.801). These results highlight strong consensus that urbanization is reshaping and degrading the wetland system.

5.1.3 Industrial or Artisanal Activities

Industrial and artisanal activities also contribute to pollution and habitat alteration. Waste discharge from small-scale industries was reported by 45 (33.8%) agreeing and 69 (51.9%) strongly agreeing (mean = 4.32, SD = 0.899). Visible landscape changes from artisanal activities were supported by 48 (36.1%) agreeing and 65 (48.9%) strongly agreeing (mean = 4.30, SD = 0.816). Disposal of industrial residues near water channels had 69 (51.9%) agreement and 44 (33.1%) strong agreement (mean = 4.14, SD = 0.760). Limited enforcement of waste control was also reported by 44 (33.1%) agreeing and 64 (48.1%) strongly agreeing (mean = 4.26, SD = 0.850). These findings indicate moderate-to-high perceived industrial impact on wetland quality.

5.1.4 Solid Waste Disposal Methods

Solid waste management emerged as one of the most critical issues. Open dumping near the wetland was confirmed by 40 (30.1%) agreeing and 83 (62.4%) strongly agreeing (mean = 4.51, SD = 0.745). Uncollected waste entering water channels during rainfall showed full agreement, with 50 (37.6%) agreeing and 83 (62.4%) strongly agreeing (mean = 4.62, SD = 0.486). Insufficient waste collection services were reported by 30 (22.6%) agreeing and 88 (66.2%) strongly agreeing (mean = 4.47, SD = 0.884). Most importantly, 15 (11.3%) agreed and 103 (77.4%) strongly agreed that poor waste disposal is a major cause of pollution (mean = 4.62, SD = 0.784). These results show near-unanimous recognition of waste management failure as a key pollution driver.

5.1.5 Sanitation Infrastructure and Practices

Sanitation conditions further worsen wetland contamination. Lack of proper toilets was reported by 30 (22.6%) agreeing and 88 (66.2%) strongly agreeing (mean = 4.51, SD = 0.794). Wastewater discharge into drains had similar results, with 30 (22.6%) agreeing and 88 (66.2%) strongly agreeing (mean = 4.55, SD = 0.690). Poor sanitation increasing contamination risk was supported by 35 (26.3%) agreeing and 83 (62.4%) strongly agreeing (mean = 4.51, SD = 0.692). Notably, 103 (77.4%) strongly agreed that improved sanitation systems would significantly reduce pollution (mean = 4.66, SD = 0.727). These findings highlight sanitation infrastructure as a key intervention point.

5.1.6 Resource Exploitation (Peat, Sand, etc.)

Resource extraction activities also contribute to wetland degradation. Habitat disturbance from peat and sand extraction was reported by 45 (33.8%) agreeing and 73 (54.9%) strongly agreeing (mean = 4.40, SD = 0.788). Increased water turbidity was supported by 30 (22.6%) agreeing and 83 (62.4%) strongly agreeing (mean = 4.40, SD = 0.921). Frequent resource collection for livelihoods had 29 (21.8%) agreeing and 94 (70.7%) strongly agreeing (mean = 4.63, SD = 0.621). Limited monitoring of extraction activities was reported by 29 (21.8%) agreeing and 84 (63.2%) strongly agreeing (mean = 4.41, SD = 0.921). These results show that resource dependence, combined with weak regulations, contributes significantly to wetland decline.

Figure 2: Anthropogenic Activities in Rugeramigozi Wetland Buffer

5.1.6 Land Use changes as an Effect of Anthropogenic Activities

Land use and land cover changes around Rugeramigozi Wetland indicate significant landscape transformation driven by human activities such as agriculture, settlement expansion, and resource use. Between 2005 and 2025, cropland declined from 397.27 ha (84%) to 295.27 ha (63%), showing a reduction in agricultural dominance possibly due to land pressure, degradation, or conversion to other uses. In contrast, built-up areas increased from 0 ha (0%) in 2005 to 20.86 ha (4%) in 2025, reflecting growing urbanization and settlement expansion around the wetland. Forest cover also increased slightly from near zero (0.03 ha, ~0%) to 31.22 ha (7%), which may indicate some reforestation or natural regeneration efforts.

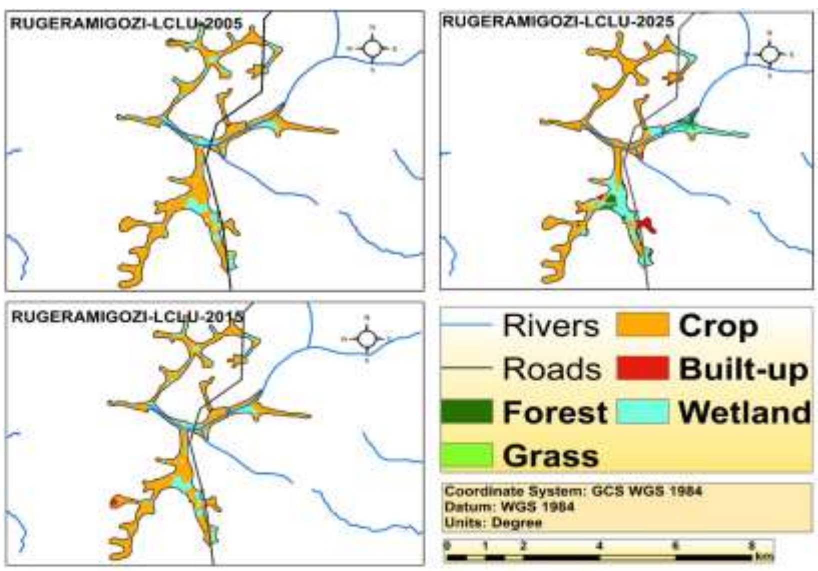
Table 1: Land Use changes as an Effect of Anthropogenic Activities 2005, 2015 and 2025

Class	2005		2015		2025	
	Area(ha)	**%**	**Area(ha)**	**%**	**Area (ha)**	**%**
Built up area	0.00	0%	3.55	1%	20.86	4%
Cropland	397.27	84%	354.25	75%	295.27	63%
Forest	0.03	0%	1.36	0%	31.22	7%
Glassland	0.05	0%	0.09	0%	0.01	0%
Wetland	74.88	16%	112.99	24%	124.88	26%
Total	**472.24**	**100%**	**472.24**	**100%**	**472.24**	**100%**

Source: Land Use / Land Cover (LULC), QGIS, 2026

Wetland area itself expanded from 74.88 ha (16%) in 2005 to 124.88 ha (26%) in 2025, suggesting possible hydrological expansion or conservation-related recovery, while grassland remained negligible throughout the period. Overall, these spatial trends demonstrate a clear shift in land use structure, where increasing settlement and changing agricultural patterns are reshaping the landscape. The results highlight the strong link between anthropogenic pressures and changes in land cover dynamics, ultimately affecting the ecological balance and functionality of Rugeramigozi Wetland.

Figure 3: Land Use / Land Cover (LULC) of Rugeramigozi, 2005, 2015 and 2025



Source: Author, Geospatial Data Analysis (2025)

5.2 Water Quality of Rugeramigozi Wetland

Water quality assessment of Rugeramigozi Wetland shows that anthropogenic activities are significantly influencing its physical, chemical, and biological conditions, although most measured parameters remain within national standards (RS 110:2017). Laboratory results indicate that pH varies from slightly acidic to near-neutral (5.07–6.27), with the lowest value in the agricultural zone (5.07), suggesting the influence of fertilizer and pesticide runoff. Turbidity levels remain below the standard limit of 30 NTU but vary widely across sites, from 2.55 NTU in the agricultural zone to 21.15 NTU in the waste and sanitation area, indicating localized sediment and pollution inputs. Electrical conductivity is highest in industrial (327.25 µS/cm) and waste-affected sites (197.05 µS/cm), reflecting increased dissolved ions from industrial effluents and domestic wastewater. Similarly, chemical oxygen demand (COD) remains within acceptable limits but is elevated in industrial and waste zones (96 mg/L), confirming higher organic pollution loads compared to agricultural and urban areas (32 mg/L).

Table 2: Spatial Variation of Water Quality Indicators Under Different Land Use Practices in Rugeramigozi Wetland

Parameter	**Unit**	**Standard (RS 110:2017)**	**S1 (Agriculture)**	**S 2 (Urban)**	**S 3 (Industrial)**	**S 4 (Waste & Sanitation)**	**S 5 (River)**
pH	–	5 – 9	5.07	5.67	5.66	5.94	6.27
Turbidity	NTU	≤ 30	2.55	3.75	13.85	21.15	14.45
Electrical Conductivity	µS/cm	–	116.1	111.5	327.25	197.05	196
COD	mg/L	≤ 250	32	32	96	96	64
Total Nitrogen	mg/L	≤ 30	7.8	10	8.025	7.6	6.7
Total Phosphorus	mg/L	≤ 5	0.25	0.16	0	0.21	0.17

Source: Laboratory, Primary Data, 2026

Nutrient analysis shows moderate enrichment of total nitrogen (6.7–10 mg/L) and low phosphorus levels (0.00–0.25 mg/L), with the highest nitrogen concentration recorded in the urban site (10 mg/L), indicating inputs from household wastewater and agricultural runoff. Overall, spatial variations in these indicators highlight pollution hotspots linked to human settlements, particularly industrial and sanitation-related zones. These laboratory findings confirm that while the wetland has not yet exceeded regulatory thresholds, cumulative anthropogenic pressures are altering its chemical balance and ecological functioning.

Complementary to laboratory data, farmer perceptions strongly confirm a decline in water quality over time. A large majority (77.4%) strongly agreed that water has become more turbid (mean = 4.77), while 63.2%–77.4% reported increased debris, reduced clarity, and changes in water flow (means = 4.48–4.55). Farmers also reported strong agreement that chemical runoff from agriculture affects water quality (mean = 4.44), and that odor, algal growth, and contamination have increased (means = 4.29–4.44). Across all chemical and physical indicators, mean scores consistently remained above 4.2, showing strong consensus on deterioration.

Perceptions of biological and health-related impacts further reinforce these findings, with respondents reporting waterborne diseases, fecal contamination from livestock, and unsafe water conditions for domestic use (means ≈ 4.22–4.44). Overall, both laboratory measurements and community perceptions converge to show that Rugeramigozi Wetland is experiencing gradual but clear water quality degradation driven by agriculture, urbanization, industrial activity, poor sanitation, and waste disposal practices. This alignment between scientific data and local knowledge highlights urgent need for integrated management interventions to protect wetland water resources and ecological health.

5.3 Role of Policies in regulating use of wetland and water quality management

Policies and institutional mechanisms play a moderate but uneven role in regulating activities around Rugeramigozi Wetland and protecting water quality. Respondents indicated that local authorities do enforce wetland protection laws (mean = 3.86) and that government initiatives have helped control destructive activities (mean = 4.14), although many also noted that violations are rarely reported or penalized (mean = 4.11), pointing to enforcement gaps. Awareness of existing regulations was relatively low and inconsistent (mean = 3.63), showing weak dissemination among residents. Community-based efforts were viewed more positively, with respondents reporting involvement in monitoring activities (mean = 3.99), recognition of local groups in reporting illegal activities (mean = 4.07), and strong agreement that environmental education has improved awareness (mean = 4.17). The strongest consensus was that increasing community participation would significantly improve wetland protection (mean = 4.46). Overall, the findings suggest that while policies exist and have some positive influence, their effectiveness is constrained by weak enforcement and limited awareness, making stronger community engagement and better implementation essential for improving wetland management and water quality.

5.4 Relationship between identified anthropogenic activities and changes in water quality of Rugeramigozi Wetland

The section on the relationship between identified anthropogenic activities and changes in the water quality of Rugeramigozi Wetland focuses on examining how human activities around the wetland influence its ecological status, particularly water quality. This analysis investigates the strength and significance of associations between various independent variables such as agricultural intensity, urbanization, industrial activities, waste management, sanitation practices, and resource exploitation and the dependent variable, water quality, while also considering the mediating role of policies and community-based monitoring programs. The aim is to quantify these relationships, identify the most impactful drivers of water quality degradation, and link these findings to the broader objectives of sustainable wetland management and environmental protection.

Table 3: Correlations between anthropogenic activities and changes in water quality of Rugeramigozi Wetland

Correlations			
		Anthropogenic Activities in Rugeramigozi Wetland	**Water Quality in Rugeramigozi Wetland**
Anthropogenic Activities in Rugeramigozi Wetland	Pearson Correlation	1	.549**
	Sig. (2-tailed)		.000
	N	133	133
Water Quality in Rugeramigozi Wetland	Pearson Correlation	.549**	1
	Sig. (2-tailed)	.000	
	N	133	133
**. Correlation is significant at the 0.01 level (2-tailed).			

By Table 3, the analysis of the relationship between identified anthropogenic activities and changes in the water quality of Rugeramigozi Wetland provides crucial insights into the study's third specific objective: to analyze how human activities influence water quality. Table 4.12 shows a significant positive correlation ($r = 0.549$, $p < 0.01$) between overall anthropogenic activities and water quality changes. This indicates that increased human activities around the wetland are strongly associated with deterioration in water quality. In the context of the study hypotheses, this result allows us to reject the null hypothesis that anthropogenic activities have no significant effect on water quality, thereby confirming that human interventions are a major driver of wetland degradation.

Table 4: Correlation over tested indicators on both independent and dependent sides

		Physical Parameters	**Chemical Parameters (Organic Maters and Nutrients)**	**Implementation of Wetland Protection Laws**	**Community-Based Environmental Monitoring Programs**
	Pearson Correlation	.545**	.117	.060	.062

		Physical Parameters	Chemical Parameters (Organic Maters and Nutrients)	Implementation of Wetland Protection Laws	Community-Based Environmental Monitoring Programs
Agricultural Practices Intensity	Sig. (2-tailed)	.000	.179	.491	.477
	N	133	133	133	133
Urbanization and Settlement Density	Pearson Correlation	.299**	-.073	.036	.088
	Sig. (2-tailed)	.000	.399	.684	.311
	N	133	133	133	133
Industrial or Artisanal Activities	Pearson Correlation	-.068	.302**	.130	-.058
	Sig. (2-tailed)	.433	.000	.135	.508
	N	133	133	133	133
Solid Waste Disposal Methods	Pearson Correlation	.557**	.175*	.010	.483**
	Sig. (2-tailed)	.000	.043	.906	.000
	N	133	133	133	133
Sanitation Infrastructure and Practices	Pearson Correlation	.425**	.412**	.414**	.102
	Sig. (2-tailed)	.000	.000	.000	.243
	N	133	133	133	133
Resource exploitation (peat, sand, etc.)	Pearson Correlation	.170*	.575**	.191*	.229**
	Sig. (2-tailed)	.050	.000	.027	.008
	N	133	133	133	133
Implementation of Wetland Protection Laws	Pearson Correlation	.172*	.269**	1	-.110
	Sig. (2-tailed)	.047	.002		.204
	N	133	133	133	133
Community-Based Environmental Monitoring Programs	Pearson Correlation	.209*	.049	-.110	1
	Sig. (2-tailed)	.015	.576	.204	
	N	133	133	133	133

Table 4 examines correlations between specific types of anthropogenic activities and detailed water quality indicators, which aligns directly with hypotheses H_{01} and H_{02} regarding physical and chemical parameters. Agricultural practices intensity shows a strong positive correlation with physical water quality parameters ($r = 0.545$, $p < 0.01$) and a significant but moderate correlation with parameters ($r = 0.220$, $p < 0.05$). This is consistent with the primary questionnaire data (Table 4.13), where 77.4% of farmers strongly agreed that wetland water appears turbid or muddy, and 63.2% noted floating debris, indicating that agricultural runoff contributes to both physical and microbial water deterioration.

Industrial or artisanal activities exhibit a significant positive correlation with chemical parameters ($r = 0.302$, $p < 0.01$), reflecting the introduction of pollutants and industrial residues into the wetland. However, they show weak or negative correlations with physical parameters. Solid waste disposal methods are strongly correlated with physical parameters ($r = 0.557$, $p < 0.01$) contamination ($r = 0.292$, $p < 0.01$), confirming that improper waste management, open dumping, and uncollected solid waste directly contribute to water turbidity and microbial hazards. Sanitation infrastructure and practices are positively correlated with both physical ($r = 0.425$, $p < 0.01$) and chemical parameters ($r = 0.412$, $p < 0.01$), showing that poor sanitation near the wetland exacerbates nutrient and microbial contamination. Resource exploitation, such as peat and sand extraction, strongly correlates with chemical ($r = 0.575$, $p < 0.01$) parameters ($r = 0.394$, $p < 0.01$), emphasizing its substantial impact on water quality deterioration.

Table 5: Model Summary Table

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.662[a]	.438	.412	.2431664
a. Predictors: (Constant), Resource exploitation (peat, sand, etc.), Industrial or Artisanal Activities, Urbanization and Settlement Density, Sanitation Infrastructure and Practices, Solid Waste Disposal Methods, Agricultural Practices Intensity				

Table 5 presents the overall model summary for the regression analysis assessing the influence of anthropogenic activities on the water quality of Rugeramigozi Wetland. The model shows a multiple correlation coefficient (R) of 0.662, indicating a moderately strong positive relationship between the combined independent variables agricultural practices intensity, urbanization and settlement density, industrial or artisanal activities, solid waste disposal methods, sanitation infrastructure and practices, and resource exploitation and the dependent variable, water quality. The R^2 value of 0.438 indicates that approximately 43.8% of the variation in water quality is explained by these anthropogenic activities collectively. After adjustment for the number of predictors, the adjusted R^2 is 0.412, suggesting that the model remains robust in explaining a significant portion of water quality variability. The standard error of the estimate (0.243) reflects the average deviation of the observed water quality values from the predicted values by the regression model. Overall, this model confirms that human activities significantly influence the wetland's water quality.

Table 6: ANOVA Table

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5.862	6	.977	16.523	.000[b]
	Residual	7.509	127	.059		
	Total	13.371	133			
a. Dependent Variable: Water Quality in Rugeramigozi Wetland						
b. Predictors: (Constant), Resource exploitation (peat, sand, etc.), Industrial or Artisanal Activities, Urbanization and Settlement Density, Sanitation Infrastructure and Practices, Solid Waste Disposal Methods, Agricultural Practices Intensity						

Table 6 reports the ANOVA results, testing the overall significance of the regression model. The regression sum of squares (5.862) compared to the residual sum of squares (7.509) indicates that the variation explained by the model is substantial relative to unexplained variation. The calculated F-value of 16.523 with a significance level of 0.000 ($p < 0.001$) confirms that the regression model is statistically significant. This means that, collectively, the independent variables anthropogenic activities have a significant effect on changes in water quality in Rugeramigozi Wetland. In the context of the study hypotheses, this provides strong evidence to reject the null that anthropogenic activities do not influence water quality, aligning with the findings from both laboratory analyses and community perception surveys.

Table 7: Table of Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.177	.427		2.757	.007
	Agricultural Practices Intensity	.261	.120	.211	2.180	.031
	Urbanization and Settlement Density	-.077	.067	-.107	-1.153	.251
	Industrial or Artisanal Activities	-.033	.049	-.048	-.672	.503
	Solid Waste Disposal Methods	.146	.057	.214	2.583	.011
	Sanitation Infrastructure and Practices	.181	.053	.256	3.437	.001
	Resource exploitation (peat, sand, etc.)	.240	.048	.357	5.032	.000
a. Dependent Variable: Water Quality in Rugeramigozi Wetland						

$Y=1.177+0.261X1-0.077X2-0.033X3+0.146X4+0.181X5+0.240X6$ (See Xs which reflect to the indicators in independent variable side).

Table 7 presents the regression coefficients for each predictor, showing both unstandardized (B) and standardized (Beta) values, along with their statistical significance. The constant term ($B = 1.177$, $p = 0.007$) represents the estimated water quality score when all independent variables are zero. Among the anthropogenic activities, agricultural practices intensity has a positive and significant effect ($B = 0.261$, $\beta = 0.211$, $p = 0.031$), indicating that increased intensity of farming practices contributes to deterioration of water quality. Solid waste disposal methods ($B = 0.146$, $\beta = 0.214$, $p = 0.011$) and sanitation infrastructure and practices ($B = 0.181$, $\beta = 0.256$, $p = 0.001$) also show significant positive impacts, reflecting the influence of poor waste management and inadequate sanitation on water quality parameters. Resource exploitation such as peat and sand extraction has the strongest effect ($B = 0.240$, $\beta = 0.357$, $p < 0.001$), indicating that unsustainable resource removal is a major contributor to water quality degradation.

Conversely, urbanization and settlement density ($B = -0.077$, $p = 0.251$) and industrial or artisanal activities ($B = -0.033$, $p = 0.503$) do not have significant effects in this model, suggesting that their influence on water quality may be indirect or mediated through other activities such as waste disposal or agricultural runoff. These findings corroborate the study's primary data, where farmers highlighted agricultural practices, poor sanitation, solid waste disposal, and resource exploitation as the main drivers of wetland water deterioration.

The regression analysis confirms that specific anthropogenic activities significantly determine water quality in Rugeramigozi Wetland, validating the study hypotheses H_{01} and H_{02} for the key contributing activities, while pointing to the need for targeted management of farming, waste, sanitation, and resource extraction practices.

Based on the findings, the study provides strong evidence supporting the link between anthropogenic activities and changes in water quality of Rugeramigozi Wetland, directly addressing the study's specific objectives. The significant positive correlation ($r = 0.549$, $p < 0.01$) between overall anthropogenic activities and water quality confirms that human actions meaningfully influence wetland conditions. Further analysis of individual activities shows that agricultural practices, poor solid waste disposal, inadequate sanitation infrastructure, and resource exploitation are the most influential factors, as indicated by significant coefficients in the regression model (B-values ranging from 0.146 to 0.261, $p < 0.05$), while urbanization and industrial/artisanal activities were not statistically significant predictors. These results validate the objectives of assessing the main anthropogenic activities affecting the Rugeramigozi Wetland (Objective i), determining water quality status (Objective ii), and analyzing the relationship between these activities and water quality changes (Objective iii).

Consequently, the hypotheses H_{01} and H_{02} which posited that anthropogenic activities have no significant effect on the physical, chemical, of water quality, are rejected. The laboratory results and community perceptions indicate deterioration in pH, turbidity, nutrient levels, safety linked to human activities, confirming that anthropogenic pressures are indeed a key driver of wetland water quality changes. This emphasizes the urgent need for targeted interventions in agricultural practices, waste management, sanitation, and resource extraction to safeguard the ecological integrity of Rugeramigozi Wetland.

5.4 Findings from Focus Group Discussions (FGDs)

The FGDs conducted with 10 Environmental and agricultural officers (group 1) and 8 Local leaders and community committee members (group 2) provided qualitative insights that complement the survey and laboratory findings, reinforcing the observed relationships between human activities and water quality degradation in Rugeramigozi Wetland. Participants consistently identified agriculture, settlement expansion, poor solid waste disposal, and resource extraction (such as peat, sand, and reeds) as the primary anthropogenic pressures affecting the wetland. Officers highlighted that over the past decade, intensified crop cultivation, livestock grazing near the wetland edge, and uncontrolled use of fertilizers have markedly increased nutrient runoff, corroborating the quantitative results where total nitrogen and phosphorus were elevated in agricultural zones and where perception surveys reported strong agreement among farmers that fertilizer use has contributed to wetland deterioration. These observations echo Katusiime and Barakagira (2025), who noted that agricultural practices elevate organic pollution in wetlands, particularly COD levels, even when other parameters remain within acceptable limits.

Settlement growth and urbanization were also emphasized as contributors to wetland stress, particularly through indiscriminate dumping of household waste, encroachment on wetland buffers, and localized artisanal or industrial activities. These qualitative accounts support the laboratory findings of higher turbidity and conductivity in urban and industrial areas and align with Umwali et al. (2021), who observed that human settlements increased nutrient loads and turbidity in Lake Muhazi. Community members and environmental officers noted that waste accumulation, particularly plastics and organic matter, frequently enters the wetland, accelerating microbial contamination and creating health risks, which is consistent with the survey results where parameters showed strong heterogeneity and significant correlations with sanitation practices and solid waste disposal.

Regarding water quality changes, participants reported visible deterioration in color and clarity, periodic odor, and algae proliferation in some wetland zones. Several officers referenced community reports of waterborne diseases, echoing the survey findings where farmers perceived the wetland as increasingly unsafe for domestic and agricultural use. These qualitative observations support quantitative correlation results indicating that anthropogenic activities are significantly associated with changes in physical and chemical water quality, and mirror findings from Tenywa et al. (2024), who found that human settlement and waste management directly influence microbial contamination of water sources.

On policy implementation and community response, FGD participants recognized the existence of wetland protection laws and environmental regulations, but noted challenges in enforcement due to limited manpower, inadequate resources, and low awareness among residents. Environmental officers reported that violations, such as encroachment and illegal resource extraction, often go unreported or are weakly penalized, resonating with the survey findings, where enforcement effectiveness and awareness of laws showed moderate mean scores with considerable heterogeneity. Community-based monitoring groups were acknowledged to play a positive role in reporting violations and educating residents, yet their effectiveness was constrained by limited funding and inconsistent participation. Participants recommended enhancing policy enforcement, promoting environmental education, and involving local communities more actively in conservation proposals that align with the empirical evidence indicating that policy and community interventions can moderate the negative effects of anthropogenic activities on water quality.

In sum, the FGD findings triangulate the quantitative results by confirming that agriculture, solid waste, sanitation practices, and resource exploitation are the key drivers of wetland degradation, that water quality deterioration is observable and affects human health, and that policy and community engagement remain critical yet underutilized tools for mitigation. These insights strengthen the study's conclusions that anthropogenic activities significantly influence physical and chemical water quality in Rugeramigozi Wetland and provide practical directions for targeted management interventions consistent with both the study objectives and prior empirical studies.

5.5 Discussion of Results

The findings of this study highlight the significant impact of anthropogenic activities on the water quality of Rugeramigozi Wetland, aligning with the first specific objective of assessing main human activities affecting the wetland. The survey results revealed that agricultural practices, urbanization, industrial and artisanal activities, poor solid waste disposal, inadequate sanitation infrastructure, and resource extraction are widespread around the wetland. Most respondents strongly agreed that these activities contribute to wetland degradation, with mean scores ranging from 4.14 to 4.81 and standard deviations indicating generally strong homogeneity or moderate heterogeneity. These results resonate with the study by Katusiime and Barakagira (2025), who observed that agricultural practices around Rwakaiha Wetland led to elevated COD levels, suggesting organic pollution, even when other parameters were within permissible limits. Similarly, the Rugeramigozi data show that nutrient enrichment and turbidity are associated with farming, solid waste, and resource exploitation, confirming that anthropogenic pressures consistently influence wetland health across different Ugandan and Rwandan contexts (Barakagira, 2025).

The water quality assessment, through both laboratory tests and farmers' perceptions, supports the second objective of determining the wetland's status. Laboratory results showed that pH ranged from 5.07 to 6.27 across different land-use zones, with turbidity and electrical conductivity highest in industrial, waste, and urban sites, indicating localized contamination. COD values were elevated in industrial and wastewater zones (96 mg/L), although remaining within RS 110:2017 guidelines. Total nitrogen and phosphorus concentrations were also higher in agricultural zones, illustrating nutrient loading. Perceptions of farmers further confirmed these patterns: most respondents strongly agreed that the wetland water had become more turbid, contained debris, exhibited odor, and showed algal growth, with mean scores between 4.26 and 4.77. These findings align with Umwali et al. (2021), who documented land-use patterns, particularly agriculture and settlements, increased nutrient loads and turbidity in Lake Muhazi, and with Sanusi et al. (2024), who found elevated TSS, TDS, and nutrient levels in surface waters under anthropogenic stress. Unlike some of the prior studies, Rugeramigozi's assessment also incorporated considerations, demonstrating that livestock, wastewater, and poor sanitation contribute to microbial contamination, thereby filling a critical knowledge gap in the empirical literature.

The correlation analyses provide strong evidence for the third objective, exploring the relationship between anthropogenic activities and water quality changes. Overall, anthropogenic activities showed a significant positive correlation with changes in water quality ($r = 0.549$, $p < 0.01$), indicating a moderate but meaningful effect. Specifically, agricultural practices intensity correlated strongly with physical parameters ($r = 0.545$, $p < 0.01$) and moderately with parameters ($r = 0.220$, $p < 0.05$), while solid waste disposal methods and sanitation infrastructure also showed significant positive correlations with both physical metrics. Resource exploitation had a strong influence on chemical parameters ($r = 0.575$, $p < 0.01$) measures ($r = 0.394$, $p < 0.01$). These results closely align with Katusiime and Barakagira (2025) regarding agricultural nutrient runoff and with Tenywa et al. (2024), who demonstrated how human settlement and sanitation influence microbial contamination in water. The Rugeramigozi findings further extend these insights by linking multiple anthropogenic sources simultaneously to both physics water quality indicators.

The regression analysis (Tables 14-16) confirms that identified anthropogenic activities collectively explain approximately 43.8% of variation in wetland water quality (Adjusted $R^2 = 0.412$), with the model being highly significant ($F = 16.523$, $p < 0.001$). Individual predictors such as resource exploitation ($B = 0.240$, $\beta = 0.357$, $p < 0.001$), sanitation infrastructure ($B = 0.181$, $\beta = 0.256$, $p < 0.001$), agricultural practices ($B = 0.261$, $\beta = 0.211$, $p = 0.031$), and solid waste disposal ($B = 0.146$, $\beta = 0.214$, $p = 0.011$) were statistically significant, confirming their direct influence on water quality. Urbanization and industrial/artisanal activities were not significant predictors, suggesting that in the Rugeramigozi context, diffuse agricultural and waste-related pressures have a stronger impact than built-up or artisanal sources. These regression results strengthen the rejection of the null hypotheses (H_{01}, H_{02}), demonstrating that anthropogenic activities significantly affect physical and chemical water quality parameters, corroborating findings from Kibira et al. (2023) and Sanusi et al. (2024) regarding ecological stress under human disturbance.

Finally, the study also examined regulatory and community interventions and found that perceptions of wetland protection policies and community-based monitoring programs were moderately positive but variable (mean scores 3.63-4.46). While enforcement exists, awareness and reporting of violations remain inconsistent, suggesting that policies and education can serve as moderate factors in managing water quality but require strengthening. This observation complements the findings from Twesigye (2025) and Mutoni (2025), highlighting that policy frameworks and local engagement are critical in mediating the effects of human activities on wetland ecosystems.

The results of the Rugeramigozi Wetland study are consistent with existing empirical literature while also extending knowledge by incorporating spatially detailed assessments of multiple anthropogenic drivers, physicochemical, water quality parameters. The study confirms that agriculture, waste disposal, sanitation, and resource exploitation are primary pressures on wetland health, that these pressures significantly degrade water quality, and that effective policy enforcement and community participation are key to mitigating such impacts. These findings directly address the study objectives and provide a robust empirical basis for targeted wetland management interventions.

6. Conclusion

The study has demonstrated that Rugeramigozi Wetland is under considerable pressure from various human activities, including intensive agriculture, settlement expansion, poor waste disposal practices, inadequate sanitation, artisanal and industrial operations, and extraction of natural resources such as sand and peat. These activities have led to observable degradation of the wetland ecosystem, with direct impacts on water quality, habitat integrity, and the overall ecological functioning of the wetland.

Laboratory analyses and community perceptions consistently revealed that the wetland's physical and chemical parameters have been compromised. Elevated turbidity, chemical oxygen demand, nutrient loads, and microbial contamination indicate that both diffuse sources (agricultural runoff, domestic wastewater) and point sources (industrial and artisanal activities) are contributing to water quality deterioration. Spatial variation in contamination patterns further highlights that areas closer to human settlements and intensive land use experience the most significant ecological stress.

Statistical analyses confirmed that human activities are significantly correlated with changes in water quality, explaining a substantial portion of the observed variation. This underscores the strong influence of anthropogenic pressures on the wetland, revealing that current land use and resource exploitation practices are unsustainable. While wetland protection policies and community-based monitoring programs exist, their enforcement remains inconsistent, limiting their effectiveness in mitigating the negative impacts.

The study establishes that Rugeramigozi Wetland is experiencing measurable ecological decline due to human activities, with compromised water quality threatening its ecological functions and the provision of essential ecosystem services. Immediate and integrated interventions combining effective policy enforcement, community engagement, and sustainable resource management are crucial to conserve the wetland and restore its environmental health.

7. Recommendations

The study recommends strengthening institutional capacity by enforcing existing wetland protection laws, improving monitoring and water quality testing systems, and developing integrated management plans that combine ecological restoration, sustainable land use, and pollution control. It also emphasizes the need to support community-based conservation initiatives through training and resources to enhance local participation in wetland protection. Farmers and wetland users are encouraged to adopt sustainable agricultural practices such as organic farming, crop rotation, contour farming, and soil conservation, while avoiding farming and livestock activities near wetland margins to reduce pollution and erosion. They are also urged to actively participate in environmental monitoring programs and awareness initiatives to promote long-term wetland sustainability. For future research, the study recommends longitudinal monitoring of water quality changes, exploration of socio-economic dependence on wetland resources, assessment of innovative restoration approaches such as buffer zones and phytoremediation, and evaluation of policy and community engagement effectiveness to inform improved wetland management strategies.

References

AACSB. (2014). *Eligibility Procedures and Accreditation Standards for Business Accreditation.* Association to Advance Collegiate Schools of Business (AACSB) International.

Abdenour, A. S. (2025). *Toward sustainable wetland management: A literature review of global wetland vulnerability assessment techniques in the context of rising pressures.* Sustainability, 17(17), Article 7962. https://doi.org/10.3390/su1717796.

Ahmed, et al. (2022). *Nutrient uptake and yield response of okra under variable irrigation water salinity.* Journal of Horticultural Science, 27(3), 150–162.

Ahmed, S. &. (2023). *Institutional frameworks and sustainable agriculture: A policy-centered analysis of Sub-Saharan Africa.* Journal of Environmental Governance, 15(1), 54–70. https://doi.org/10.1016/j.envgov.2023.01.006.

Ajzen, I. (1985). *From intentions to actions: A theory of planned behavior. In J. Kuhl & J. Beckmann (Eds.), Action Control: From Cognition to Behavior (pp. 11-39).* Heidelberg: Springer.

Aliyu, S. &. (2022). *Assessment of irrigation water quality for vegetable farming in peri-urban Kumasi.* Environmental Monitoring and Assessment, 194(5), 310–325.

Bazambanza, A. B. (2024). *Seasonal subsurface water quality variation of physicochemical characteristics in Kamutwa-Kigali, Rwanda.* Aqua–Water Infrastructure, Ecosystems and Society, 73(4), 737–745. https://doi.org/10.2166/aqua.2024.240.

Byakweli, C. I. (2021). *Buffer zones and nutrient pollution control in Rwandan wetlands.* Wetlands Ecology and Management, 29(6), 845–857.

Campbell, C. W. (2023). *Nitrate variability in irrigation water: Contribution to crop N inputs.* Journal of Environmental Quality, 52(4), 789–798.

Chandra, S. &. (2023). *Groundwater quality and paddy yield: a field-based study in southern India.* Journal of Agronomy and Water Resources, 12(1), 45–58.

Creswell, J. W. (2018). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches (5th ed.).* SAGE Publications.

Dusabimana, T. (2012). *Irrigation practices and water management in Rugeramigozi Marshland A case study of surface irrigation in Rugeramigozi.*

EEA. (2023). *Environmental signals 1999: European environment agency report on the state and prospects of the environment in Europe.* European Environment Agency (EEA).

El Behja, H. E. (2024). *Evaluating coastal lagoon sustainability through the Driver-Pressure-State-Impact-Response approach: a study of Khenifiss Lagoon, southern Morocco.* Frontiers in Earth Science.

FAO. (2024). *Global food production at increased risk from excess salt in soil.* The Guardian summary of FAO report.

FAO. (2024). *The State of the World's Land and Water Resources for Food and Agriculture.* Food and Agriculture Organization of the United Nations.

Fernandez, L. G. (2020). *Irrigation water quality and vegetable yield: evidence from rural Spain.* International Journal of Agricultural Science, 9(3), 150–162.

FES. (2020). *he impact of wastewater discharge and agriculture on water quality and nutrient retention of Namatala Wetland, Eastern Uganda.* Frontiers in Environmental Science (FES).

Gatete, E. R. (2023). *Wetland pollution monitoring in the Eastern province.* Rwanda Journal of Natural Resources, 7(1), 25–41.

GoR. (2017). *Official Gazette no 07 of 13/02/2017: Boundaries of swamp Lands and their characteristics.*

Habimana, P. U. (2024). *Farmer training and water quality outcomes under irrigation policy.* Agri-Science Review, 19(2), 89–102.

Hakuzimana, J. &. (2020). *Performance evaluation of irrigation schemes in Rugeramigozi marshland, Rwanda.* Water Conservation and Management, 4(1), 15–19.

Hassani, F. R.-M. (2021). *Pot-based study of nitrate and phosphate regimes in wheat under subsurface irrigation.* Irrigation Science, 39(2), 235–248.

Initiative, N. B. (2023). *Water Quality Monitoring Baseline Report-Rwanda.* Nile Basin Initiative.

Ishimwe, J. &. (2023). *Effects of guidelines enforcement on soil microbiota in wetlands.* Soil Biology & Biochemistry, 167, 108648.

Jahan, . U. (2024). *Impacts of climate change-induced salinity intrusion on physiological parameters of aquatic hydrophytes from coastal rivers of Bangladesh. arXiv preprint.*

Kalu, A. E. (2022). *Seasonal wetland water quality and vegetable yield in Nigeria.* Journal of Environmental Agriculture, 30(4), 210–225.

Kamanzi, E. U. (2022). *Irrigation policy implementation and water quality management in rural Rwanda.* Water Policy Journal, 14(2), 110–125.

Katusiime. (2025). *Impact of agricultural practices on the water quality of Rwakaiha Wetland, Kyegegwa District, Uganda.* Journal of Global Agriculture & Ecology, 17(3), 1-9. https://doi.org/10.56557/jogae/2025/v17i39366.

Katusiime. (2025). *Impact of agricultural practices on the water quality of Rwakaiha Wetland, Kyegegwa District, Uganda.* Journal of Global Agriculture and Ecology, 17(3), 1–9. https://doi.org/10.56557/jogae/2025/v17i39366.

Kibira, G. L. (2023). *Assessing wetland health through decomposition in degraded and semi-intact wetlands in Uganda.* Environmental Monitoring and Assessment, 195(2), Article 150. https://doi.org/10.1007/s10661-023-10836-6.

Kothari, C. R. (2014). *Research Methodology: Methods and Techniques (3rd ed.).* New Age International Publishers.

Kristensen, P. (2004). *The DPSIR framework. National Institute for Public Health and the Environment (RIVM), Bilthoven.*

Liang, H. &. (2021). *Heavy metal contaminated irrigation water effects on rice germination and yield.* Environmental Toxicology and Crop Safety, 14(2), 102–115.

Macháček, J. (2020). *Alluvial artisanal and small-scale mining in a river stream Rutsiro case study (Rwanda).* Forests, 11(7), 762. https://doi.org/10.3390/f11070762.

Martins, J. F. (2023). *Phosphate and heavy metals in irrigation water: impact on lettuce growth.* Brazilian Journal of Agricultural Research, 18(3), 300–314.

Modu, M. &. (2020). *Effects of urbanization on wetland ecosystem and aquatic biodiversity in Makurdi Metropolis, Nigeria.* Sustainability and Biodiversity Conservation. https://doi.org/10.5281/zenodo.13996596.

Msutu, B. (2019). *Salinity and nutrient impacts on maize growth in Tanzania.* East African Journal of Crop Science, 6(1), 35–46.

Mugisha, F. &. (2023). *Impact of National Irrigation Policy on canal maintenance in Rwanda.* Irrigation and Drainage, 11(1), e1456.

Muhanga District. (2025). *District annual Report 2024.* Muhanga District, Southern Province, Rwanda.

Munyaneza, A. &. (2022). *Agrochemical regulation compliance in wetland buffer zones.* Environmental Management, 49(4), 543–557.

Mutoni, C. &. (2025). *Assessment of the impacts of climate variability on surface water quality of Nyabarongo River, Rwanda.* Environmental Challenges, 9, 100849. https://doi.org/10.1016/j.envc.2024.100849.

Mwangi, P. O. (2023). *Irrigation water quality effects on maize productivity in Uganda.* African Journal of Irrigation Science, 5(2), 78–90.

Nabahungu, N. L. (2020). *Farmers' knowledge and perception of agricultural wetland in Rwanda (Cyabayaga & Rugeramigozi).* Land Degradation & Development.

Ndayisaba, J. M. (2022). *Assessing agricultural runoff impacts on wetland water quality in Southern Rwanda.* African Journal of Ecology, 60(3), 245–258.

Ndirangu, T. K. (2022). *Wetland irrigation water quality and vegetable yield in Kenya.* Journal of Horticultural Water Management, 8(1), 55–70.

Ndoli, S. B. (2024). *Electrical conductivity trends in protected wetlands.* Journal of Soil and Water Conservation, 79(1), 37–46.

Nigatu, W. K. (2015). *Quantitative assessment of the chemical safety of groundwater wells in Bugesera and Muhanga districts of Rwanda.* International Journal of Environmental Protection and Policy, 3(4), 104–110.

NISR. (2025). *Household Living Condition Survey 2024 (EICV7).* Kigali, Rwanda: National Institute of tatistics of Rwanda (NISR).

Niu, S. L. (2023). *Process analysis and mitigation strategies for wetland degradation caused by increasing agricultural water demand: an ecology–economy nexus perspective.* Ecological Processes, 12(1), Article 40. https://doi.org/10.1186/s13717-023-00452.

Niyonzima, F. &. (2021). *National irrigation policy compliance and water pollution in Rwanda.* Environmental Policy and Governance, 31(4), 303–318.

Nsanzabaganwa, J. C. (2025). *Impact analysis of constructed wetland for wastewater management in Rwanda.* Frontiers in Environmental Science, 13, Article 1559624. https://doi.org/10.3389/fenvs.2025.1559624.

Nsanzimana, G. N. (2022). *Community irrigation committees and water quality in Rwanda.* Development Policy Review, 40(3), 245–260.

Nsengiyumva, J. N. (2021). *Geospatial analysis for heavy metals and water quality assessment in Bugesera agricultural wetlands of Rwanda.* Rwanda Journal of Engineering, Science, Technology and Environment, 4(1).

Nyenje, P. M. (2021). *Human activities and their impact on water quality in African wetlands.* Environmental Monitoring and Assessment, 193(4), 1–14.

Ostrom. (2007). *Institutional rational choice: An assessment of the Institutional Analysis and Development Framework. In P. A. Sabatier (Ed.),.* Theories of the Policy Process (2nd ed., pp. 21-64). Westview Press.

Ostrom, E. (2021). *Institutional Analysis and Development: Principles and Approaches.* Annual Review of Environment and Resources, 46, 1-24.

Perez-Martinez, E. R. (2022). *Electrical conductivity and wheat performance in Mexico.* Crop Water Use Journal, 11(2), 112–120.

REMA. (2021). *Rwanda environment management authority wetlands information.*

REMA. (2023). *Wetlands: Natural and irrigated. Rwanda Water Portal.* Rwanda Environment Management Authority (REMA)/ Retrieved from https://waterportal.rwb.rw/toolbox/465.

Rwanda Vision 2050. (2020). *National Strategy for Transformation and Sustainable Development.* Ministry of Finance and Economic Planning.

Samuel, R. S. (2023). *Drip irrigation water quality and crop growth in India.* Agricultural Water Management Today, 17(1), 23–36.

Sanusi, M. I. (2024). *Water quality assessment of selected water sources in Kampala and Mbarara districts, Uganda, using water quality index and multivariate statistics.* Environmental Advances, 16, 100360. https://doi.org/10.1016/j.envadv.2024.100360.

Sekomo, B. et al. (2025). *Review: Current groundwater monitoring practices in Rwanda.* Hydrogeology Journal.

Shibru, T. (2024). *Evaluation of kikuyu grass wetland for wastewater treatment efficiency from malt factory, Ethiopia.* BMC Public Health, 24, Article 2031. https://doi.org/10.1186/s12889-024-19496-5.

Smith, L. &. (2021). *Reassessing environmental determinism in the context of agricultural sustainability.* Environmental Systems Research, 10(2), 103–115. https://doi.org/10.1186/s40068-021-00225-x.

Tenywa, F. O. (2024). *Assessing the sanitary and limnochemical quality of spring water sources in a flood-prone area of Kampala, Uganda.* International Journal of Environmental Health Research, 34(1), 45–60. https://doi.org/10.1080/09603123.2023.2206791.

Twesigye, C. K. (2025). *Effect of land use activities on water quality and vegetation cover change in Nsooba-Lubigi wetland system, Kampala City.* African Journal of Environmental Science and Technology, 19(2), 35–46. https://doi.org/10.5897/AJEST2025.3123.

Umwali, E. N. (2021). *Spatio-seasonal variation of water quality under land use land cover change of Lake Muhazi, Rwanda.* Water Practice and Technology, 16(2), 482–496. https://doi.org/10.2166/wpt.2021.041.

UN Environment Program. (2020). *National Wetlands Management Framework for Rwanda: Final Report, December 2020.* University of Rwanda: By the Centre of Excellence in Biodiversity and Natural Resource Management.

UNEP. (2023). *Global Environment Outlook 7: Healthy Planet, Healthy People.* United Nations Environment Programme.

Uwizeye, A. &. (2022). *Sanctions and reduced pollution in Rwandan wetlands.* Environmental Protection Journal, 13(2), 202–214.

World Bank. (2022). *Water quality challenges in Sub-Saharan Africa: Policy perspectives and future pathways.*

Zhang, Y. &. (2022). *Abiotic stress and crop growth: A physiological approach to yield optimization*. Plant Science Innovations, 28(3), 245–260. https://doi.org/10.1016/j.plantsci.2022.03.012.