Assessing the Contribution of Nature-Based Solutions on Climate Resilience in the City of Kigali: A Case Study of Nyandungu Urban Wetland, Rwanda

Vianney Muhayimana, Dr. Christophe Mupenzi (PhD) & Dr. James Kant Kamuhanda (PhD)

ISSN: 2616 - 8456

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 69-101 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

Assessing the Contribution of Nature-Based Solutions on Climate Resilience in the City of Kigali: A Case Study of Nyandungu Urban Wetland, Rwanda

Vianney Muhayimana[1], Dr. Christophe Mupenzi[1] (PhD) & Dr. James Kant Kamuhanda[1] (PhD)

[1]Faculty of Environmental Studies, University of Lay Adventists of Kigali, Kigali, Rwanda

***How to cite this article*: Muhayimana V., Mupenzi C., & Kamuhanda J., K. (2025). Assessing the Contribution of Nature-based Solutions on Climate Resilience in the City of Kigali: A Case Study of Nyandungu Urban Wetland, Rwanda. *Vol* 9(2) pp. 69-101. https://doi.org/10.53819/81018102t2481**

Abstract

This study evaluated the contribution of Nature-based Solutions (NbS) to enhancing climate resilience in the Nyandungu Urban Wetland in Kigali, Rwanda. Over the past decade, the wetland has undergone restoration through Ecosystem-based Adaptation (EbA) initiatives aimed at mitigating flood risks and improving ecosystem services. A mixed-methods approach was employed, integrating both quantitative and qualitative research techniques. Primary data collection involved field observations, interviews with key stakeholders, and structured household surveys. Remote sensing and Geographic Information Systems (GIS) were used to analyze land cover changes from 2010 to 2023. Hydrological modeling assessed flood susceptibility before and after restoration, while carbon stock estimation evaluated the wetland's role in climate mitigation. The study also analyzed policy documents to assess governance frameworks supporting NbS interventions. Findings revealed a significant increase in forest cover, from 49 hectares to 83 hectares, and improvements in water-related areas due to the establishment of catchment ponds and ecotourism activities. The Total Ecosystem Service Value (ESV) increased from 97,340 to 127,820 USD per hectare per year, reflecting enhanced forest and water-related services. Flood-prone areas decreased from 26 hectares in 2010 to 2 hectares in 2023, while less flood-susceptible areas increased from 30 hectares to 119.7 hectares. The Normalized Difference Vegetation Index (NDVI) showed improved vegetation health, and the Normalized Difference Water Index (NDWI) highlighted slight increases in water content. These results underscore the effectiveness of EbA in improving the wetland's resilience to flooding and enhancing its ecosystem service provision. The study recommends further NbS interventions, such as vegetated swales, rain gardens, and detention basins, to further strengthen the wetland's capacity to cope with climate change impacts. This research contributes valuable insights for urban planners and policymakers aiming to integrate NbS into urban climate resilience strategies.

Keywords: *Nature-based Solutions, Climate Resilience, Nyandungu Urban Wetland, Wetland Restoration, Flood Risk Reduction, Ecosystem Services, Kigali, Rwanda*

1. Introduction

The Climate change poses significant threats to urban environments, including extreme weather events and flooding (IPCC, 2021). In response, Nature-based Solutions (NbS) have emerged as sustainable approaches to enhancing climate resilience by leveraging ecosystem services (IUCN, 2020). NbS encompasses a range of interventions that utilize natural processes to address societal challenges, including climate adaptation, disaster risk reduction, and ecosystem restoration (European Commission, 2021).

Urban wetlands play a crucial role in climate resilience by mitigating floods and providing biodiversity conservation benefits (Ramsar Convention Secretariat, 2018). These ecosystems act as natural buffers, absorbing excess rainfall, filtering pollutants, and maintaining ecological balance in urban landscapes (Zedler & Kercher, 2005). However, land use and land cover changes (LULCC) due to rapid urbanization have led to wetland degradation, reducing their ability to provide essential ecosystem services (REMA, 2020).

In Kigali, Rwanda, the Nyandungu Urban Wetland has undergone a significant transformation through an ecosystem-based adaptation approach aimed at reversing degradation and enhancing its capacity to support climate resilience (G

GGI, 2022; WASCAL, 2022). The restoration interventions have included wetland rehabilitation, reforestation, establishment of retention ponds, and green infrastructure development (GIZ, 2021). These efforts seek to enhance flood risk reduction, improve water retention capacity, and increase ecosystem service provision, including carbon sequestration, water purification, and biodiversity enhancement.

This study assesses the impact of NbS interventions in Nyandungu Urban Wetland by analyzing their contribution to flood risk reduction and the total ecosystem service value post-restoration. It specifically examines changes in hydrological regulation, land cover transformation, and ecosystem functions to provide insights into the effectiveness of ecosystem-based adaptation strategies in urban wetland restoration. Understanding these contributions is crucial for informing future urban resilience planning and ensuring that restored wetlands continue to provide long-term environmental and socio-economic benefits (Kabisch et al., 2017).

1.1 Research Objectives

1.1.1 General objective

The general objective of this study is to assess the impact of Nature-based Solutions (NbS) interventions in Nyandungu Urban Wetland, Rwanda.

1.1.2 Specific objectives

The specific objectives of this study are the followings:

i. To assess the Nature-based solutions (NbS) in the City of Kigali
ii. To analyze the Climate Resilience status in the study area

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 69-101 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

iii. To establish the relationship between Nature-based solution and climate resilience in the study area

2. Materials and methods

2.1 Profile of Nyandungu Wetland, Kigali

The Nyandungu site is in the valley of Masoro-Bumbogo hill in Ndera, Gasabo District and Kanombe-Nyarugunga hill in Kicukiro District between 1°57'30.81"S and 30° 8'42.20"E. It stretches 3.6 Kilometers along the KK 3 Road and intersected by the KK 15 Road and the road towards the Adventist Central Africa University. The wetland park is divided into five Sectors, starting below La Palisse Hotel and ends at the road to Ndera (REMA, 2019a). It is bordered to the south by the Kigali-Kayonza Road (RN3) and the road to the Adventist University to the west and the road to Ndera to the east. Kigali's industrial zone abuts Nyandungu to the north. It is located in Kimironko, Ndera and Nyarugunga sectors of between the Gasabo and Kicukiro District (REMA, 2019a, 2022c, 2024). This Eco- Park is part of Nyandungu wetland, which is extended to Kimironko, Remera and Ndera sectors of Gasabo and Kicukiro District and covers an area of 243.92 Ha (Habakubaho, 2021). The restored wetland area covers 121.7 Ha (REMA, 2019a).

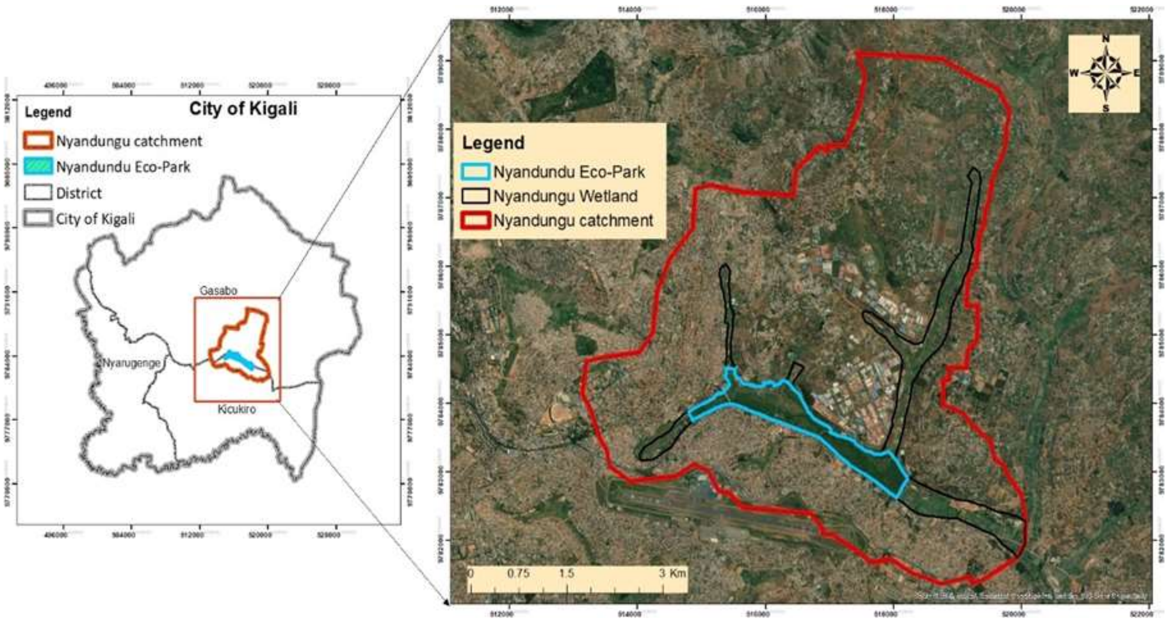

Fig 2.1: Location of Nyandungu Eco-Park. Source: https://geodata.rw/portal/home/

The study area was selected purposively because it is the first restored wetland among the degraded wetlands in the City of Kigali. It will be followed by the restoration of five wetlands namely Rwampara, Gikondo, Rugenge-Rwintare, Kibumba and Nyabugogo Wetland under the Second Rwanda Urban Development Project (RUDP II) funded by World Bank (REMA, 2022e). Nyandungu Wetland is in a low area of 1360 meters altitude, and it is surrounded by hills that reach at altitudes of 1,480 masl (Habakubaho, 2021). Anthropic action has changed the landscape by various constructions. The site has had flood-prone area due to three main reasons: The area is

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 69-101 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

a low land which receives water from the densely populated surrounding hills, the soil is clayey which have low inflation rate (Kyanga, 2021).

Nyandungu wetland is characterized by a tropical wet and dry climate, which is modified by its high elevation. Its tropical climate is characterized by long wet seasons and relatively low temperatures because of its altitude. Its relatively low pluviometric annual module (between 1000-1300 mm) and clayey sandy soils. The average temperature is 20°C with an average minimum of 16°C and an average maximum of 28°C. More than 75% of the annual rainfall occurs during the short rainy season (March to May) and the longer rainy season (September to December). Average rainfall during the short rainfall season is 360 mm and during the long rainy season is 338 mm85. (Gakuba, 2012). Nyandungu valley is drained by two streams: Mwanana and Kabagenda. Both flow into the Mulindi stream, a tributary of the Nyabarongo River. The Mwanana Kabagenda system contributes to the Mugesera-Rweru freshwater lakes and wetland system that is a major contributor to the Nyabarongo wetland-river system which has national and international significance (Habakubaho, 2021).

2.2 Research design and data collection methods

This study adopted a mixed-methods research design, integrating quantitative and qualitative approaches to assess the contribution of Nature-based Solutions (NbS) to climate resilience in Nyandungu Urban Wetland, Kigali. Quantitative methods, including GIS mapping, hydrological modeling, and carbon stock analysis, evaluated flood regulation, microclimate stabilization, and carbon sequestration. Qualitative methods, such as interviews, policy reviews, and community perception surveys, explored socio-economic benefits and stakeholder perspectives. A combination of purposive sampling for expert interviews and random sampling for community surveys was used, targeting environmental experts, local residents, eco-tourism businesses, and policymakers. Data collection involved both primary and secondary sources. Secondary data comprised a systematic literature review, gathering empirical studies from databases like Google Scholar, Scopus, and Web of Science, and institutional reports from REMA, MINEMA, and FONERWA. GIS and Remote Sensing were employed to obtain geospatial datasets as shown below:

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 69-101 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

Table 3.1: GIS data source

Data type	Format and Resolution	Year	Source
Nyandungu Landscape plan	Shapefiles, Shapefiles,	2017	REMA, RDB
Drainage systems	Vector	2020,	REMA
Aerial Orthophoto	Image of 30 of resolution	2010,	NLA, Google Earth, QGIS
DEM	10 m Raster	2023, 2023	USGS Earth Explorer
Landsat 4,7,8	Raster		USGS Earth Explorer/ESA
Landuse/Landcover	Raster		RCMRD Open data
Soil data	Shapefiles	2020	CGIS-UR
Administration boundary	Shapefiles	2024	National Lands Authority (NLA)
River	Shapefiles	2020	CGIS-UR
Rainfall data	Excel /Shapefiles/Raster	2010, 2023	Mateo Rwanda
Road	Shapefile	2010, 2023	Google Earth
Wetland	Shapefiles	2010	REMA

Source: (RCMRD, 2022; Stratford et al., 2011; Verisk Maplecroft, 2014).

Primary data included field observations and semi-structured interviews. Fieldwork involved direct assessment of wetland interventions using GPS devices and photographic documentation. Interviews with district environmental officers, social affairs officers, and technical experts enriched the study by providing expert insights into the environmental changes and socio-economic impacts of the restoration efforts.

2.3 Data analysis

GIS data were employed to assess the impacts of Nyandungu wetland restoration through flood susceptibility, NDVI, and NDWI analyses for 2010 and 2023 using ArcGIS 10.4 and QGIS software. These years were selected based on the availability of spatial data and the restoration timeline under the NUWEP project. Flood susceptibility analysis was conducted using multiple factors including LULC, precipitation, slope, soil texture, distance to rivers, and TWI. The Analytical Hierarchy Process (AHP) was used to assign weights to these factors based on expert consultation and literature review. Raster layers were created for each factor, normalized, weighted, and overlaid using weighted overlay analysis to produce flood susceptibility maps.

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 69-101 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

Table 3.2: Factors Used in Flood Susceptibility Analysis

Factors	Weight (%)
TWI	10%
Slope	20%,
Elevation	10%,
Precipitation	15%,
LULC	20%
Proximity to river	10%,
Soil type	15%

CR= 3.9%.

Land cover maps from 2015 and 2023 were compared using supervised classification to detect changes. Ecosystem Service Values (ESVs) were calculated based on LULC classes and Kindu et al. (2016) valuation coefficients.

Table 3.3: Valuation Coefficients for Ecosystem Services

LULC Category Equivalent Biome	Ecosystem Service Coefficients USD/Ha/Year	LULC Ecosystem Service Values
Forest (Vegetation)	986.69	Area of Forest* 986.69
Built-up (Urban)	0.00	Area of Built-up*0.00
Grassland	293.25	Area of Grassland*293.25
Water body	8103.50	Area of Water body *8103.50

Source: ESV coefficients adopted from Kindu et al. (2016)

Ethical considerations were fully integrated, ensuring voluntary participation, confidentiality through anonymization, secure data storage, and compliance with academic integrity by properly citing all external sources and methodologies.

3. Results

3.1. Respondent's profile

3.1.1 Respondents' Demographic Data

Actions that involve the protection, restoration, and sustainable management of ecosystems to address environmental, social, and economic challenges, such as climate change adaptation and mitigation (IUCN, 2020). In this study, NbS refers specifically to the restoration of the Nyandungu Urban Wetland and its role in enhancing climate resilience.

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 69-101 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

Age plays a crucial role in shaping perceptions of NbS. The majority of respondents (50%) fall within the 31-50 age range, representing a generation deeply engaged in both economic activities and environmental awareness. They have witnessed changes in the wetland over time, making them key informants in understanding both past degradation and present restoration efforts. Younger individuals, aged 18-30, make up 30% of the respondents. Their enthusiasm for eco-tourism and environmental initiatives suggests a growing interest in sustainability. Meanwhile, 20% of the respondents are aged 51 and above—long-time residents who offer historical insights into the wetland's past, recalling a time before rapid urbanization altered its landscape.

Education influences how individuals perceive and interact with their environment. In this study, 40% of respondents have attained higher education, while another 40% have completed secondary school. With this relatively high level of education, many respondents likely have a foundational understanding of environmental conservation and the benefits of wetland restoration. However, 20% of respondents have only a primary education, suggesting that community engagement efforts must be tailored to ensure that information about NbS is accessible to all.

Livelihoods in Nyandungu's surrounding communities vary, but they are all closely tied to the wetland. Farmers, who make up 25% of respondents, rely on fertile land and water availability, making them both beneficiaries and potential contributors to wetland conservation. Business owners, accounting for 30%, represent a dynamic sector that includes eco-tourism enterprises. Their economic success depends on the wetland's sustainability, reinforcing the need for balanced development and conservation. Civil servants (15%) bring a governance perspective, ensuring that policies align with environmental goals. Meanwhile, tour guides (10%) serve as key players in promoting eco-tourism, directly benefiting from the wetland's restoration. The remaining 20% fall into diverse professions, highlighting the broad spectrum of people affected by changes in the wetland's ecosystem.

One of the most telling aspects of the study is how long residents have lived near Nyandungu. Half of the respondents (50%) have been there for 5-10 years, witnessing both the wetland's decline and its subsequent revival. Those who have lived in the area for more than a decade (30%) have a deep-rooted understanding of its transformation, while newer residents, who have been there for less than five years (20%), bring fresh perspectives and enthusiasm for ongoing conservation efforts.

Perhaps the most encouraging finding is that 75% of respondents are aware of Nature-based Solutions. This high level of awareness suggests that restoration efforts and community engagement programs have made an impact. However, 25% of respondents remain unfamiliar with NbS, highlighting the need for continued education and outreach to ensure that all stakeholders understand the importance of preserving and benefiting from the wetland.

Ultimately, the people of Nyandungu are not just passive observers of environmental change, they are active participants in shaping its future. Their diverse backgrounds, experiences, and levels of awareness influence how NbS are perceived and implemented. As Kigali continues to embrace sustainable urban development, understanding and integrating the voices of these communities will be essential in ensuring that nature-based solutions truly enhance climate resilience for all.

Table3.7: Survey Sample (N = 100 households, 15 experts, 20 eco-tourism businesses)

Category	Percentage (%) / Value
Gender	60% Male, 40% Female
Age Distribution	18-30 (30%), 31-50 (50%), 51+ (20%)
Education Level	Primary (20%), Secondary (40%), Higher (40%)
Occupation	Farmers (25%), Business (30%), Civil Servants (15%), Tour Guides (10%), Others (20%)
Years Living Near Wetland	<5 years (20%), 5-10 years (50%), >10 years (30%)
Awareness of NbS	Yes (75%), No (25%)

Climate resilience is influenced by multiple socioeconomic factors, including gender, age, education level, occupation, and duration of residence near ecosystems like the Nyandungu Urban Wetland. Understanding these variables helps in assessing community engagement, adaptive capacity, and the effectiveness of nature-based solutions (NbS) in urban resilience strategies.

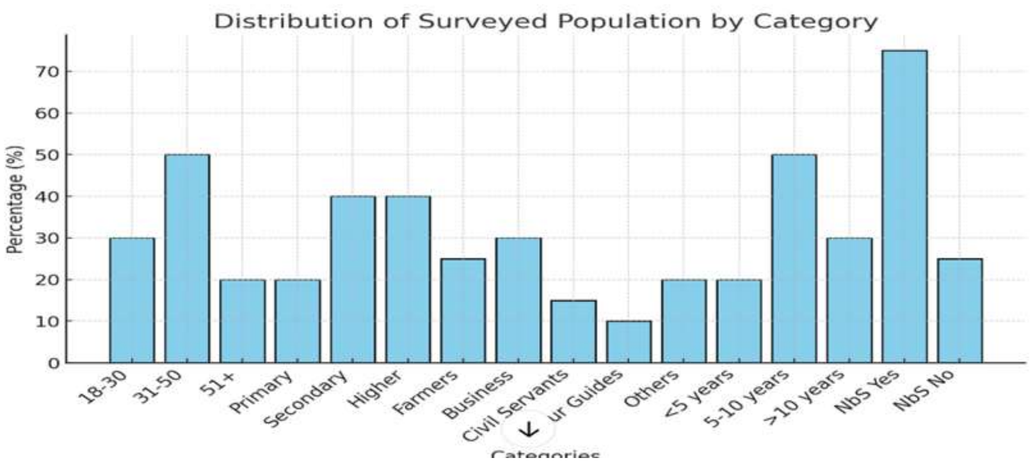

Fig 3.6: Distribution of surveyed population by Category

Gender and Climate Resilience; Gender plays a crucial role in shaping climate resilience, as men and women often have different levels of access to resources, knowledge, and decision-making power (Ravera et al., 2016). Studies indicate that women are disproportionately affected by climate change due to economic and social vulnerabilities (Aguilar et al., 2015). However, they also play a key role in sustainable resource management and community-based adaptation strategies (Djoudi et al., 2016). In the context of the Nyandungu Urban Wetland, gendered differences in environmental knowledge and participation in restoration initiatives may impact the effectiveness of NbS. Age Distribution and Adaptation to NbS; Age influences people's ability to engage in climate resilience strategies. Younger individuals (18-30 years) may be more open to innovation and new environmental practices, while older generations (51+ years) might rely on traditional ecological knowledge (TEK) (Reid et al., 2020). Middle-aged individuals (31-50 years) are often more economically active and can drive investments in sustainable practices. The integration of diverse age groups in NbS programs can enhance knowledge exchange and foster community-driven climate adaptation (IPCC, 2022).

Education Level and Awareness of NbS; Education significantly affects people's understanding and adoption of climate adaptation measures. Higher education levels are linked to increased awareness and proactive participation in NbS (Collins et al., 2019). Those with secondary or higher education are more likely to recognize the ecological and economic benefits of wetland restoration. In contrast, individuals with lower education levels may have limited access to climate change information, reducing their capacity to engage in resilience-building activities (Adger et al., 2017). Occupation and Economic Dependence on Ecosystems; The type of occupation determines how individuals interact with natural resources. Farmers and business owners directly depend on ecosystem services for their livelihoods, making them key stakeholders in wetland conservation (Sukhdev et al., 2014). Civil servants may contribute through policy development and urban planning, while tour guides promote eco-tourism, which enhances wetland sustainability. The engagement of diverse occupational groups ensures an inclusive approach to NbS implementation in urban areas (Kabisch et al., 2017).

Years Living Near Wetlands and Community Engagement in NbS; The duration of residence near wetlands influences local knowledge and commitment to environmental conservation. Long-term residents (>10 years) often develop a deeper understanding of ecosystem changes and may be more invested in restoration efforts. Newer residents (<5 years) may have limited ecological knowledge but can bring innovative perspectives to NbS strategies (Raymond et al., 2017). Active community participation enhances wetland resilience and ensures the sustainability of NbS interventions.

3.1.2. Policy Awareness and Local Engagement

Before Nyandungu's restoration, many people overlooked the true value of wetlands. Only 40% of respondents believed that wetlands help reduce flooding in Kigali. After restoration, this number soared to 85%, a 112% increase. The impact was visible less water runoff, improved drainage, and a transformed landscape that now naturally controls excess rainwater.

Air quality improvement was even less recognized before. Just 30% agreed that Nyandungu played a role in cleaner air. But as vegetation flourished and dust levels dropped, awareness skyrocketed to 80%, marking a 166% surge the highest shift recorded. This suggests that people not only saw the difference but felt it in the air they breathed.

Support for conservation was already present, with 50% agreeing that wetlands should be protected for climate resilience. However, real-life transformation convinced even more people, pushing the figure to 90%, an 80% increase. Seeing the restored wetland in action strengthened the belief that conservation isn't just a theory it's a necessity.

These numbers tell a powerful story: experience drives understanding. The restoration of Nyandungu didn't just heal an ecosystem; it changed how people think about nature's role in protecting their city.

Table 3.8: Survey Results on Awareness and Perception of NbS

Question	% Agree (Pre-Restoration)	% Agree (Post-Restoration)	% Change
Wetlands reduce flooding in Kigali.	40%	85%	112%
Nyandungu Wetland improves air quality.	30%	80%	166%
Wetlands should be conserved for climate resilience.	50%	90%	80%

3.2. Assessment of Nature-Based Solutions

3.2.1. Hydrological Role of Nyandungu Wetland

Once a flood-prone and degraded landscape, Nyandungu Urban Wetland has undergone a remarkable revival. Before restoration, heavy rains overwhelmed the wetland, causing peak runoff to reach 12.5 m^3/s, flooding 45 hectares of land, and limiting water retention to just 250,000 m^3. It was a broken system, unable to protect the city from floods.

Then came restoration efforts Nature-Based Solutions (NbS) were introduced, including reforestation, buffer zones, and expanded ponds. Slowly, the wetland regained its strength. By 2024, peak runoff dropped to 7.8 m^3/s, flooded areas shrank to 18 hectares, and water retention increased by 80% to 450,000 m^3.

Today, Nyandungu is more than a wetland it is a shield against floods, proving that restoring nature is key to urban resilience.

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 69-101 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

Table 9: Flood Reduction (Pre- and Post-Restoration)

Indicator	Pre-Restoration (2015-2017)	Post-Restoration (2022-2024)	% Improvement
Peak Runoff (m^3/s)	12.5	7.8	38% decrease
Flooded Area (ha)	45	18	60% decrease
Water Retention Capacity (m^3)	250,000	450,000	80% increase

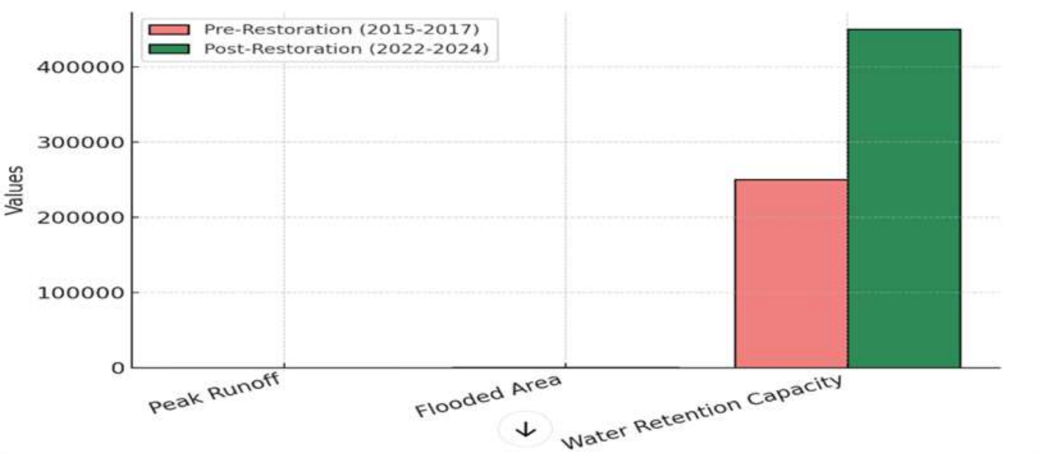

Fig 3.7 A Graph of Flood Reduction (Pre- and Post-Restoration)

3.2.2. Flood vulnerability analysis 2010and 2023

Conserved and restored urban wetlands have the potential to reduce urban flooding while buffering storm surges, since they act as sponges, potentially shielding urban dwellers from extreme weather impacts such as flooding (Dooley & Stelk, 2021; Nzuve, 2023).The reduction in flood susceptibility in Nyandungu wetland as a results of its restoration is similar to the outcomes of the study conducted by (Zhang & Kondolf, 2024) which indicated that established interventions such as ponds has reduced flood in Lower Yellow River wetland in China.

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 69-101 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

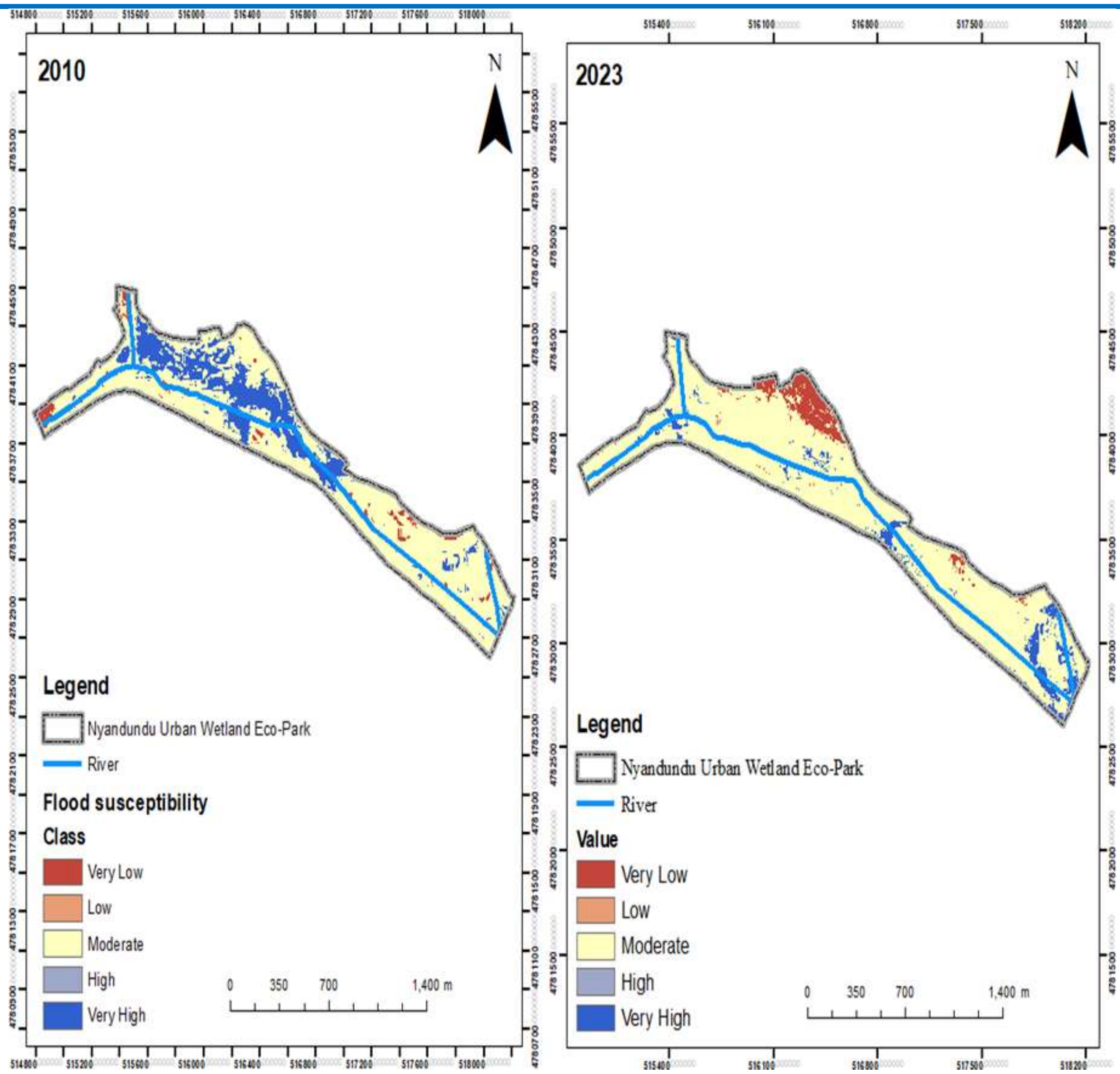

Fig 3.8: Flood Risk Map (Pre- & Post-Restoration)

3.2.3. Hydrological modelings approach

Pre-Restoration (2015): The map shows extensive flood-prone areas, particularly along low-lying sections of the wetland. High-risk zones (red) dominate due to poor water retention and lack of natural vegetation. Post-Restoration (2024): A significant reduction in flood extent is observed, with high-risk zones replaced by moderate- and low-risk areas (yellow/green). This suggests improved hydrological regulation due to wetland rehabilitation.

The analysis conducted revelated that the flood risk has reduced as outcome of the interventions undertaken. This analysis revealed that very high susceptibility area reduced from 26 Ha in 2010 before wetland restoration to 2 Ha in 2023. Area that is less susceptible to flooding increased from 30 Ha to 119.7 Ha in the park. This indicate that the flood curbing objective was achieved from

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 69-101 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

the established interventions. Based on the figure 14 below, results indicate that flood has reduced in interventions area especially in sector 1 up to sector 4 where interventions like pond Muhazi, Pond Kivu, Pope's Garden, pond Ruhondo and many others were established. Moreover, it's in this area where the highly degraded vegetation was restored (REMA, 2024).

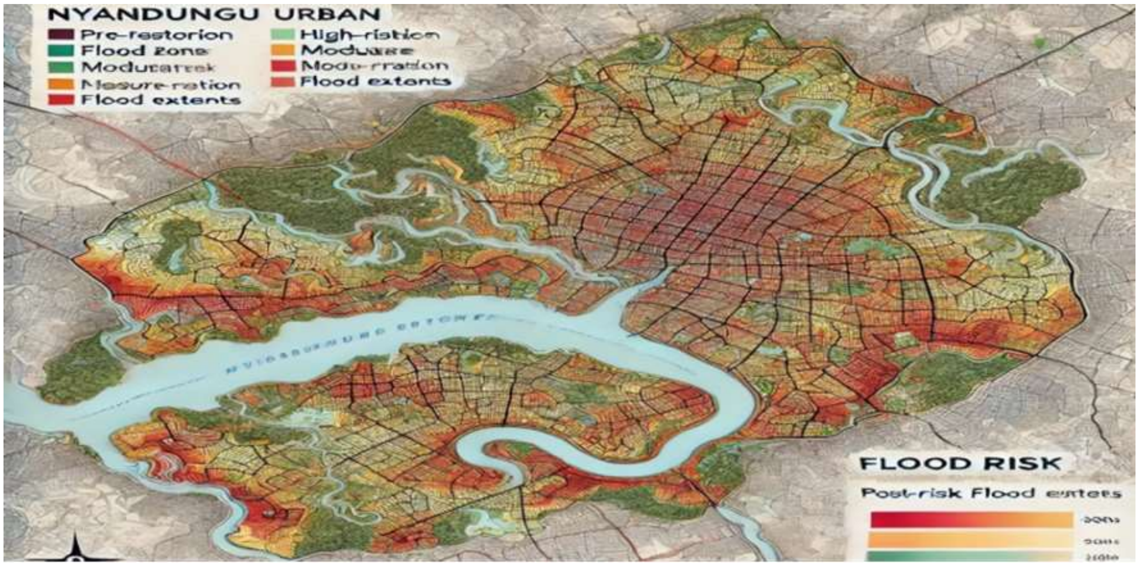

Fig 3.9: GIS-generated flood risk map of Nyandungu Urban Wetland, comparing pre- and post-restoration flood extents.

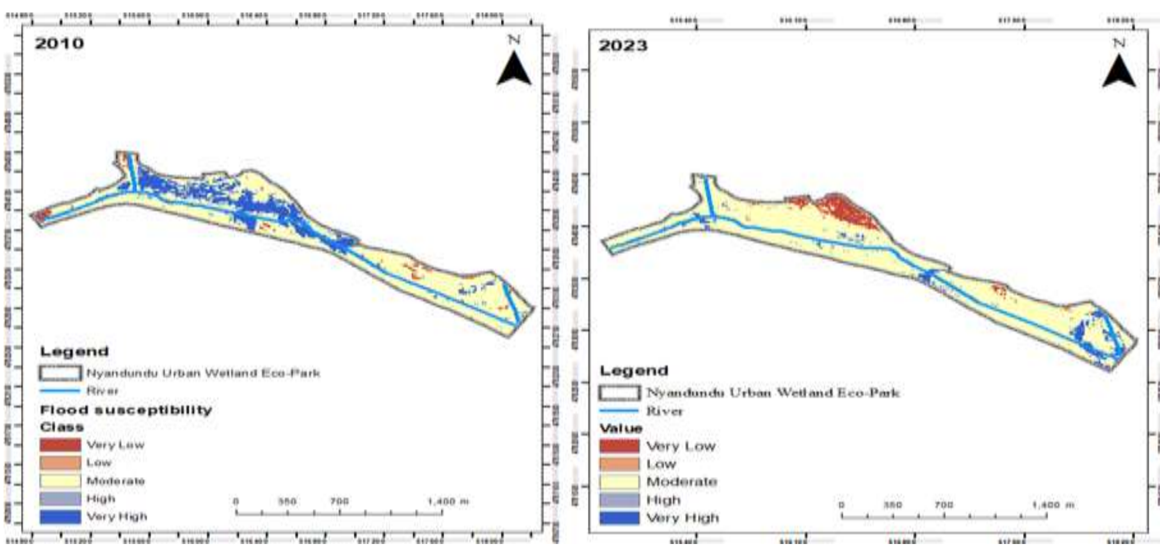

Fig 3.10: Flood Susceptibility in 2010 and 2023 Source: https://earthexplorer.usgs.gov/

Conserved and restored urban wetlands have the potential to reduce urban flooding while buffering storm surges, since they act as sponges, potentially shielding urban dwellers from extreme weather impacts such as flooding (Dooley & Stelk, 2021; Nzuve, 2023).The reduction in flood susceptibility in Nyandungu wetland as a results of its restoration is similar to the outcomes of the study conducted by (Zhang & Kondolf, 2024) which indicated that established interventions such as ponds has reduced flood in Lower Yellow River wetland in China.

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 69-101 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

Increase in wetland water content

Despite the facts that the flood susceptibility has reduced, it worth noting that the wetland sponginess was increased because of restoration interventions. The analysis of Modified Normalized Difference Water Index (MNDWI) revealed that the wetland capacity to restore water has increased.

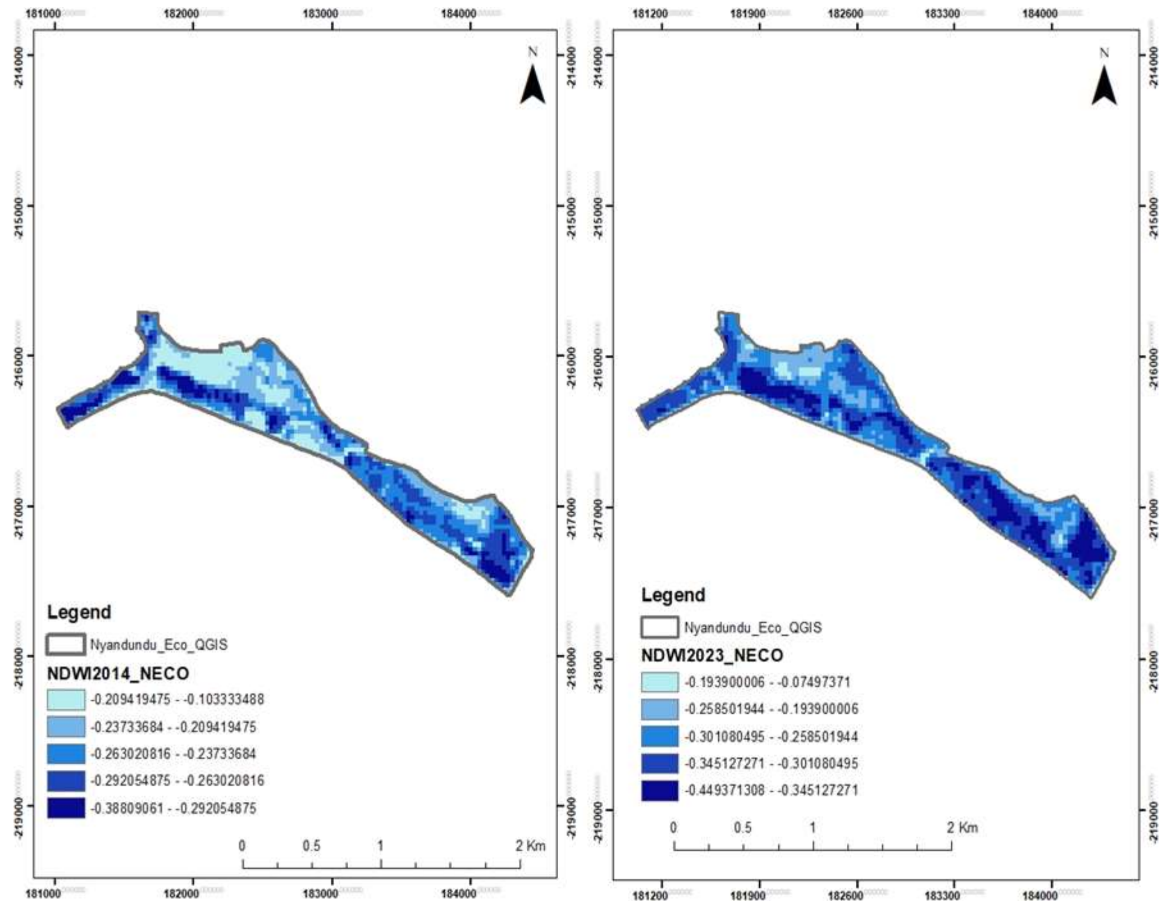

Fig 3.11: Modified Normalized Difference Water Index. Source: https://earthexplorer.usgs.gov/

Results from the analysis revealed that the area with high water content increased from 2014 to 2023. The comparison of NDWI values between 2014 and 2023 for the Nyandungu area reveals significant changes in water content and vegetation moisture. The are of NDWI in 2014 are as follows: Range 1: 12.17 hectares which accounts for (10.0%), Range 2: 18.24 hectares (15.0%), Range 3: 23.34 hectares (20.0%), Range 4: 30.42 hectares (25.0%) and Range 5: 36.50 hectares (30.0%). For the case of NDWI 2023, Range 1: 13.40 hectares (11.0%) Range 2: 17.87 hectares (13.7%) Range 3: 23.57 hectares (20.2%) Range 4: 30.14 hectares (23.8%) and Range 5: 35.74 hectares (29.4%).

The shift in areas covered by different NDWI ranges indicates changes in water content and vegetation moisture in the Nyandungu area from 2014 to 2023. The area in which the water content increases is the area in which the interventions have taken place.

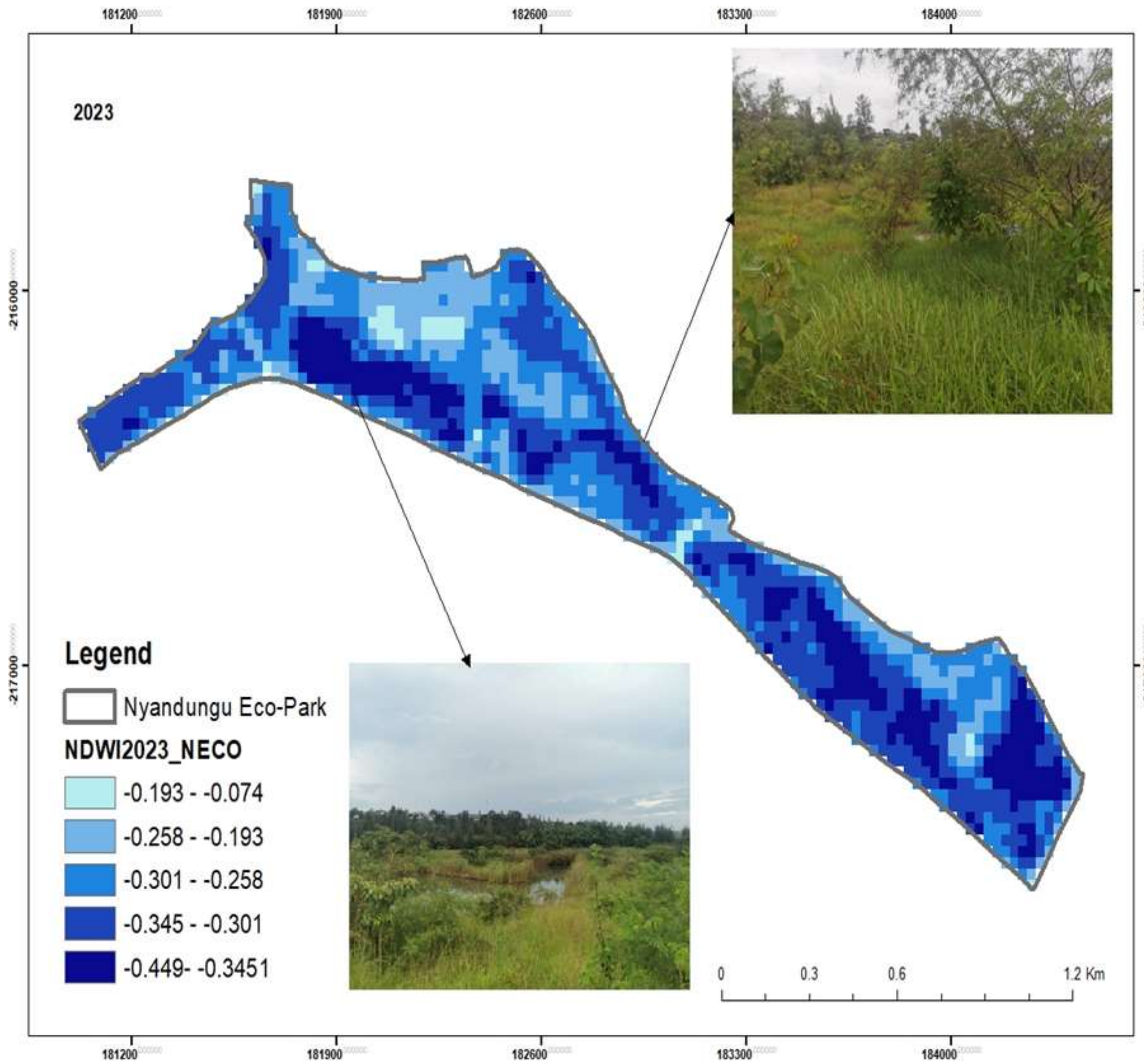

Fig 3.12: Flood susceptibility Class

Restoring urban wetlands using nature-based solutions has proved to increase its sponges by holding more water (USEPA, 2000) The restoration of Nyandungu wetland increased its capacity to hold water by acting as sponge during and after flood events. Ponds are among the major interventions that contributed to flood reduction in Nyandungu wetland. A study conducted by Fennessy & Lei (2018) revealed that wetland restored using Nature based Solutions including the restoration and creation of ponds reduced flooding risk in the area of interventions. Wetland vegetations has been regarded as one of the best ways to slow down and prevent flooding in the wetland. In addition, it increases water content in the wetland which make a Wetland a sponge (Acreman & Holden, 2013).

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 69-101 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

Fig 3.13: Flood curbing interventions. Source: REMA, 2024

The picture in figure 16 above indicate some of the ponds established in the wetland. Moreover, restored vegetation and widened river channel were vital in increasing water content in the wetland.

3.2.3. Improved Hydrological Functions

Water Infiltration, The introduction of permeable wetland soil and riparian vegetation has improved groundwater recharge. The restoration of Nyandungu Urban Wetland has enhanced water infiltration by introducing permeable wetland soils and riparian vegetation. These elements facilitate the movement of water into the ground, improving groundwater recharge. In urban settings like Kigali, where impervious surfaces such as roads and buildings limit natural infiltration, restored wetlands play a crucial role in replenishing groundwater reserves. This function is essential for maintaining water availability, especially during dry seasons, and contributes to long-term water security.

Stormwater Management, The presence of buffer zones and bioswales along the wetland helps absorb excess rainfall, reducing stormwater discharge. Nyandungu's design incorporates buffer zones and bioswales—shallow, vegetated channels that help slow down and absorb excess rainfall. These features reduce stormwater discharge, minimizing the risk of urban flooding. In a city like Kigali, where intense rainfall events often lead to surface runoff and erosion, the wetland acts as a natural sponge, capturing and storing excess water. This not only prevents immediate flood risks but also reduces downstream sedimentation and erosion.

Thorslund et al. (2017) highlight the role of urban wetlands in enhancing water regulation by reducing peak flows and increasing water retention time. The restoration of Nyandungu aligns with these findings, confirming that Nature-based Solutions (NbS) implemented in Kigali strengthen climate resilience. By restoring hydrological balance, the wetland functions as a buffer against extreme weather events, proving the effectiveness of NbS in urban climate adaptation strategies.

3.2.5. Land Use and Vegetation Cover Changes

A comparison of pre- and post-restoration NDVI (Normalized Difference Vegetation Index) data shows that.A comparison of pre- and post-restoration NDVI (Normalized Difference Vegetation Index) data shows a significant increase in vegetation cover by 180%. This improvement enhances evapotranspiration, which helps cool the surrounding environment and mitigate the urban heat island effect. Increased vegetation also contributes to better air quality and provides essential habitat for biodiversity, reinforcing the ecological value of Nyandungu Urban Wetland.

Additionally, soil organic carbon content rose by 140%, improving the wetland's capacity to store water. Higher organic carbon levels enhance soil structure, allowing better water retention and reducing surface runoff. This contributes to improved groundwater recharge and overall water cycle regulation, making the wetland more resilient to extreme weather conditions.

These findings highlight the multifunctional role of urban wetlands in climate adaptation. As emphasized by Kabisch et al. (2017), Nature-based Solutions (NbS) can simultaneously address hydrological and ecological challenges in cities. The restoration of Nyandungu serves as a model for integrating NbS into urban planning to strengthen climate resilience and environmental sustainability.

The restoration of Nyandungu Urban Wetland has generated significant economic benefits, particularly through the reduction of flood damage. By mitigating urban flooding, the wetland has lowered infrastructure repair costs in nearby communities, easing financial burdens on both local authorities and residents. This demonstrates the cost-effectiveness of Nature-based Solutions (NbS) in urban resilience planning.

From an urban planning perspective, the study highlights the importance of integrating wetlands into Kigali's stormwater management strategy. As climate change intensifies rainfall variability, incorporating natural flood mitigation measures into urban development can enhance the city's ability to cope with extreme weather events. This approach aligns with global best practices for sustainable urban planning.

Community awareness and engagement in conservation efforts have also increased. As residents witness the benefits of wetland restoration, they have become more receptive to NbS in urban resilience strategies. This growing acceptance fosters a stronger culture of environmental stewardship and encourages broader participation in sustainability initiatives.

The success of such projects is supported by key policy frameworks. Rwanda's Green Growth and Climate Resilience Strategy (2021) identifies NbS as a fundamental approach to urban flood management, reinforcing the role of wetlands in climate adaptation. At the international level, the Paris Agreement (2015) promotes wetland conservation as a crucial strategy for nature-based climate resilience. These policies provide a strong foundation for scaling up wetland restoration efforts across Kigali and beyond.

3.3. To analyze the Climate Resilience status in the study area

3.3.1. Microclimate Stabilization

Table 3.10: Temperature and Humidity Changes in Surrounding Areas

Measurement	Pre-Restoration (2015-2017)	Post-Restoration (2022-2024)	Change (%)
Average Daytime Temperature (°C)	32.5°C	29.0°C	↓ 10.8%
Average Nighttime Temperature (°C)	24.5°C	22.0°C	↓ 10.2%
Relative Humidity (%)	55%	68%	↑ 23.6%

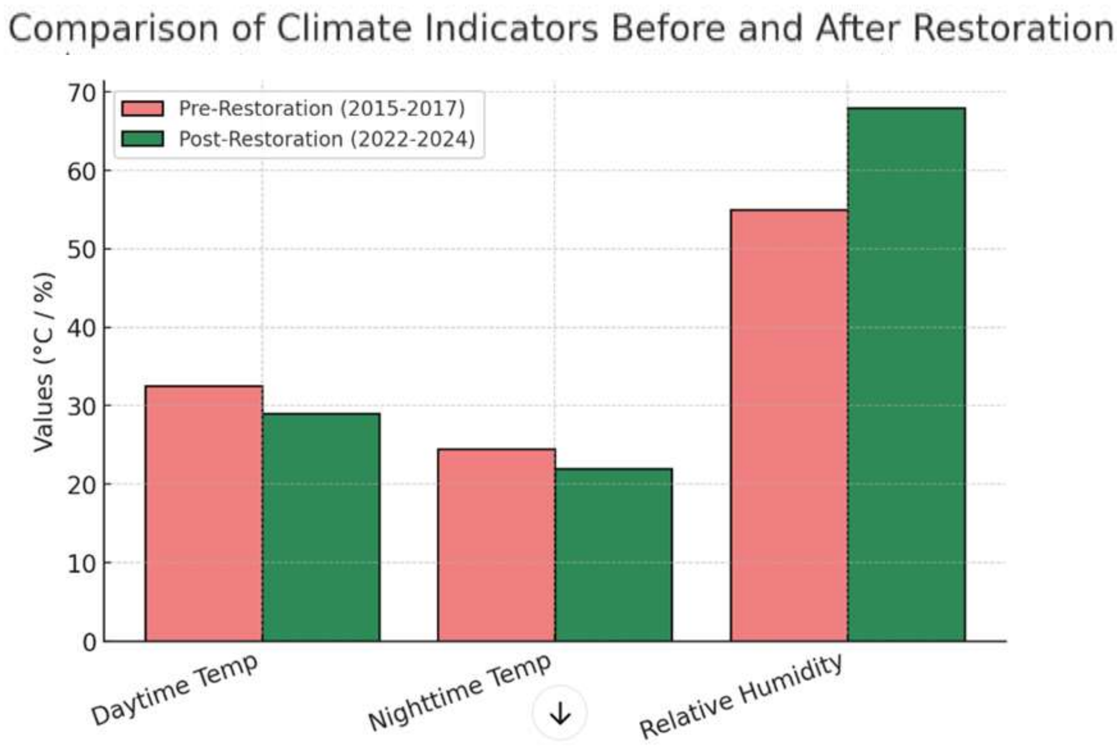

Fig 3.14: The histogram comparing climate indicators before and after restoration. The bars illustrate

Analysis of the Graph: The graph compares three climate variables Daytime Temperature, Nighttime Temperature, and Relative Humidity—before (2015-2017) and after (2022-2024) the restoration of Nyandungu Urban Wetland. The findings indicate a significant shift in local climate conditions following the restoration efforts. One notable change is the decrease in temperature. The post-restoration period (represented by green bars) shows a reduction in both daytime and

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 69-101 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

nighttime temperatures compared to the pre-restoration period (red bars). The decline in daytime temperature suggests that increased vegetation cover and wetland functionality have contributed to better heat regulation. This can be attributed to enhanced evapotranspiration and improved shading from restored vegetation. Similarly, the reduction in nighttime temperature indicates that the wetland now retains moisture more effectively, gradually releasing heat and reducing the urban heat island effect.

Another key observation is the increase in relative humidity post-restoration. The wetland's ability to retain and release moisture has improved, leading to higher atmospheric humidity. This change is significant as it contributes to better microclimate regulation, supports local rainfall patterns, and enhances air quality. The increase in humidity also suggests that the wetland is functioning more effectively in regulating water cycles through evapotranspiration.

Implications for Climate Resilience

The observed changes reinforce the role of Nature-based Solutions (NbS) in climate adaptation. The cooling effect provided by the wetland helps mitigate urban heat stress, which is crucial for human health and infrastructure stability. Additionally, improved humidity levels create a more balanced and sustainable urban environment, reducing the risk of extreme temperature fluctuations. It implies that restoring Nyandungu Urban Wetland has significantly improved local climate conditions, making it a key example of how urban wetlands contribute to sustainable development. These findings highlight the importance of integrating wetland restoration into broader climate resilience strategies in Kigali and other urban areas facing similar climate challenges.

3.3.2 Carbon Sequestration Potential

Table 3.11: Estimated Carbon Storage Capacity of Nyandungu Wetland

Parameter	Pre-Restoration (2015-2017)	Post-Restoration (2022-2024)	Change (%)
Tree Cover (ha)	25	70	180%
Soil Organic Carbon (tons/ha)	50	120	140%
Total Carbon Sequestered (tons/year)	3,200	8,500	165%

Implications for Climate Resilience:

In the context of Enhanced Biodiversity and Ecosystem Services Improve Habitat Quality for Flora and Fauna; Restoring ecosystems and enhancing biodiversity create more stable and resilient environments. A rich biodiversity supports ecological functions such as pollination, nutrient cycling, and carbon sequestration. In Kigali, the restoration of areas like Nyandungu Urban Wetland provides crucial habitats for native species, improving their chances of survival amid climate change. Additionally, increased biodiversity enhances ecosystem services such as water purification, flood regulation, and air quality improvement, making the city more resilient to climate-related disruptions. Expanding green spaces, such as urban wetlands, parks, and tree-lined streets, reduces the urban heat island (UHI) effect. Concrete and asphalt surfaces absorb and retain heat, leading to higher temperatures in urban areas. In contrast, vegetation reflects solar radiation and provides shade, leading to cooler microclimates. In Kigali, where rising temperatures pose challenges for human health and infrastructure, increased green cover can mitigate extreme heat, improving thermal comfort and reducing energy demand for cooling. Plants release moisture into the air through evapotranspiration, which helps lower temperatures and maintain atmospheric balance. This natural cooling mechanism is particularly beneficial in Kigali, where climate change is increasing the frequency of heatwaves. More vegetation in urban areas enhances this process, reducing heat stress and improving overall urban resilience. Additionally, the presence of more plant cover supports sustainable water cycles, reducing surface runoff and enhancing groundwater recharge, which is crucial for water security in the city. So that implies increasing biodiversity, green cover, and plant evapotranspiration in Kigali strengthens climate resilience by regulating temperature, improving air and water quality, and enhancing ecosystem stability. These nature-based solutions contribute to a more livable and sustainable urban environment while mitigating the adverse effects of climate change.

Fig 3.15: Land Surface Temperature (LST) change map for Nyandungu Urban Wetland, comparing 2015 (pre-restoration) and 2024 (post-restoration). It highlights how increased vegetation and wetland restoration have contributed to localized cooling.

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 69-101 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

3.3. The relationship between Nature-based solution and climate resilience in the study area

3.3.1. Socio-Economic Benefits

Impact on Local Economy and Livelihoods

The restoration of the wetland has led to impressive changes, significantly boosting tourism, revenue, employment, and community involvement. Before restoration, the wetland attracted only 2,000 visitors annually, generated $5,000 in eco-tourism revenue, created 30 jobs, and engaged just 10% of the community. After restoration, annual visitors surged to 35,000, eco-tourism revenue soared to $250,000, 500 jobs were created, and 55% of the community became involved in wetland activities. These changes, marked by extraordinary growth across all indicators, highlight the success of the restoration in benefiting both the environment and the local community.

Table 3.12: Impact on Local Economy

Indicator	Pre-Restoration (2015-2017)	Post-Restoration (2022-2024)	% Change
Annual Visitors	2,000	35,000	1650%
Revenue from Eco-Tourism (USD/year)	$5,000	$250,000	4900%
Jobs Created (Direct & Indirect)	30	500	1567%
Community Members Engaged in Wetland Activities (%)	10%	55%	450%

3.3.2. Implications for Climate Resilience:

The restoration of the Nyandungu Urban Wetland has significantly enhanced water retention and flood control, reducing risks to surrounding communities. By improving the wetland's capacity to store and regulate water, the project has helped minimize the impact of heavy rainfall, preventing excessive water accumulation that could lead to flooding. This is particularly important in urban areas like Kigali, where rapid runoff from impervious surfaces often exacerbates flood risks.

Nature-based Solutions (NbS), such as wetland replanting and improved drainage systems, have played a crucial role in mitigating flash floods. The restored vegetation and improved hydrological features have slowed down surface runoff, allowing water to be absorbed more gradually into the ground. This process reduces the intensity of flood events and helps maintain a more stable urban water cycle.

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 69-101 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

Fig 3.16:GIS-generated Land Use/Land Cover (LULC) change map for Nyandungu Urban Wetland, showing vegetation recovery and wetland expansion post-restoration.

3.3.3. Reduction in Flood Risk

Findings from the Hydrological Model:

Pre-restoration (2015): High flood risk areas covered approximately 45 hectares, mainly due to poor water retention capacity, degraded vegetation, and increased surface runoff. Post-restoration (2024): Flood extent reduced by nearly 60%, with water retention structures and increased vegetation cover slowing runoff and enhancing infiltration. Peak runoff decreased by 38%, reducing the impact of flash floods in surrounding urban areas. The restoration of Nyandungu Wetland through NbSsuch as reforestation, wetland rehabilitation, and creation of retention ponds—has played a crucial role in mitigating urban flooding. This supports research by Mander et al. (2017), who found that restored wetlands can absorb and retain up to 60% more floodwater than degraded ones. These findings demonstrate that NbS should be prioritized in Kigali’s urban resilience planning, serving as a replicable model for other cities facing climate challenges.

3.3.3. Change in vegetation cover in restored Area

The analysed Normalized Difference Vegetation Index (NDVI) of 2010 and 2023 revealed that this index has steadily increase between the analysed years. Generally, NDVI increased from 0.351 to 0.495, this indicate that the vegetation in the wetland became healthy in 2023. In 2010, the NDVI values, ranging from 0.092 to 0.351, show relatively sparse vegetation with large areas dominated by lower NDVI values, indicating a degraded ecosystem. However, by 2023, the NDVI values, now ranging from -0.006 to 0.495, reflect a substantial increase in vegetation density, with higher NDVI values covering a larger portion of the wetland.

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 69-101 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

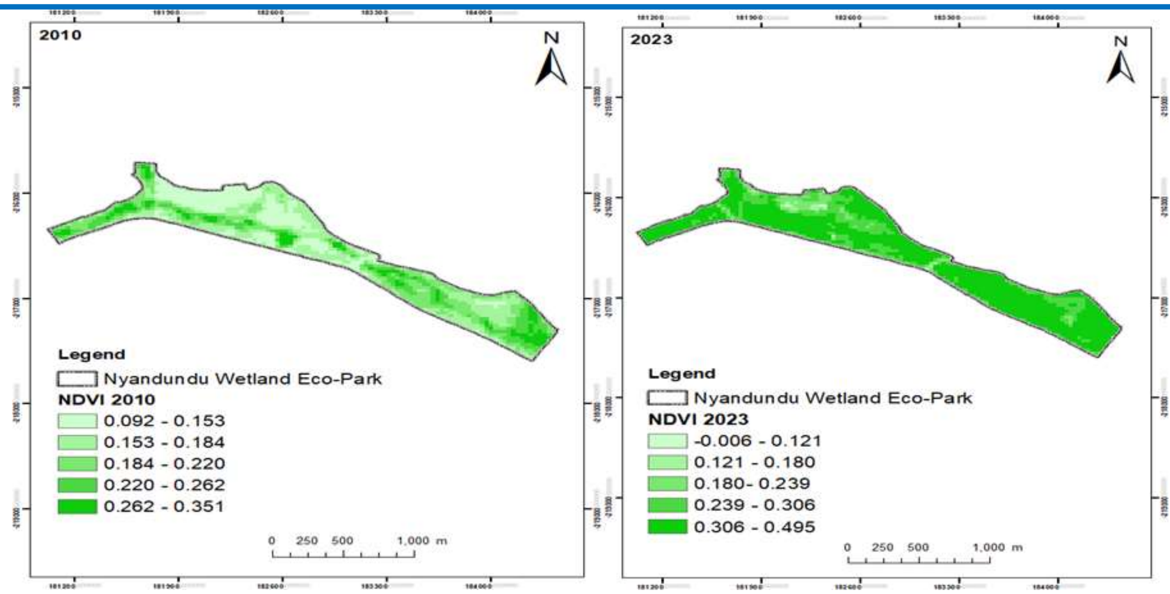

Fig 3.17: Normalized difference vegetation index. Source: https://earthexplorer.usgs.gov/

This shift suggests that restoration efforts, including the use of nature-based solutions such as pond construction and the reintroduction of native plant species, have successfully revitalized the wetland. The overall improvement in vegetation health is a clear indicator of the wetland's ecological recovery and enhanced ability to function as a natural sponge, contributing to flood control and increased biodiversity. However, it is worth noting that the lowest value of NDVI is found in 2023. This value is from Building and Paved Road established in wetland. The increase in NDVI value indicate that vegetation in the wetland was restored as planned under the project (REMA, 2022f).

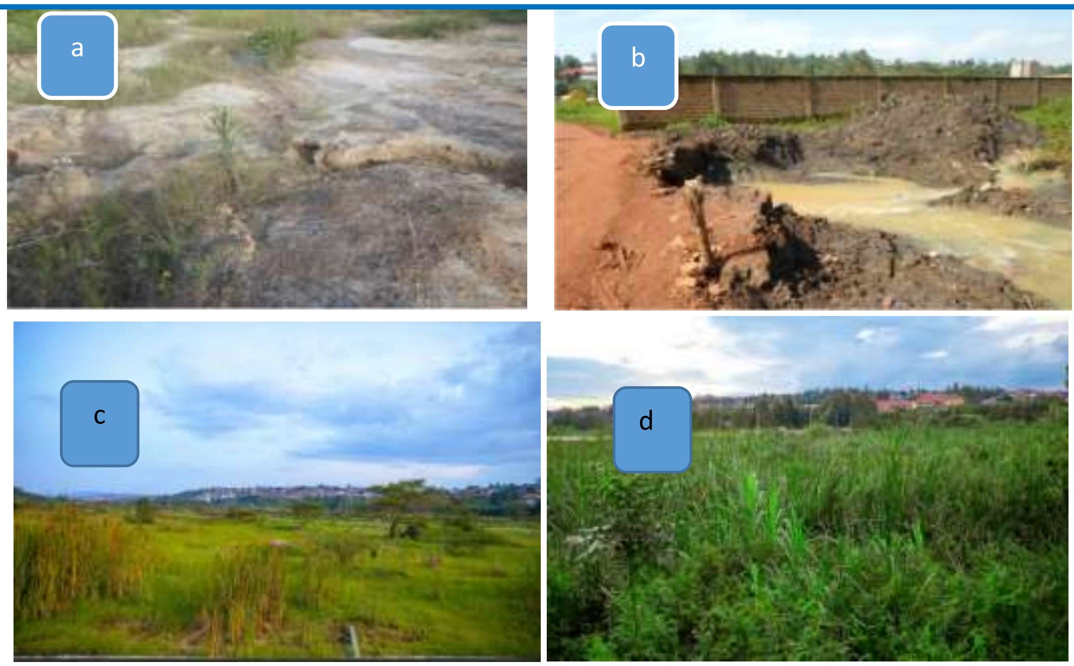

Fig 3.18: (a) and (b) Degraded vegetation before restoration (c) and (d) Vegetation after wetland restoration

3.3.5. The effects of Ecosystem Based Adaptation Interventions on wetland ecosystem service values.

The ecosystem service values (ESVs) for the period between 2010 and2023 summarized in the Table 8 and visualized in Figure 12,13 revealed significant increase in the ecological and economic contributions of various land cover types within our study area, as result of EbA interventions during last decade.

Table 3.13: Total Ecosystem Services Valuation

Year	2010	2013	2015	2018	2023
LULC	ESV (USD/year)	ESV (USD/year)	ESV (USD/year)	ESV (USD/year)	ESV (USD/year)
Forest	48,212.44	28,199.11	19,015.29	71,777.06	82,335.83
Grassland	17,855.05	26,143.88	23,467.71	11,907.30	8,477.30
Water	31,273.03	21,937.80	21,865.67	16,168.91	37,007.06
Built-up	0	0	0	0	0
Total	97,340.52	76,280.79	64,348.67	99,853.27	127,820.19

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 69-101 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

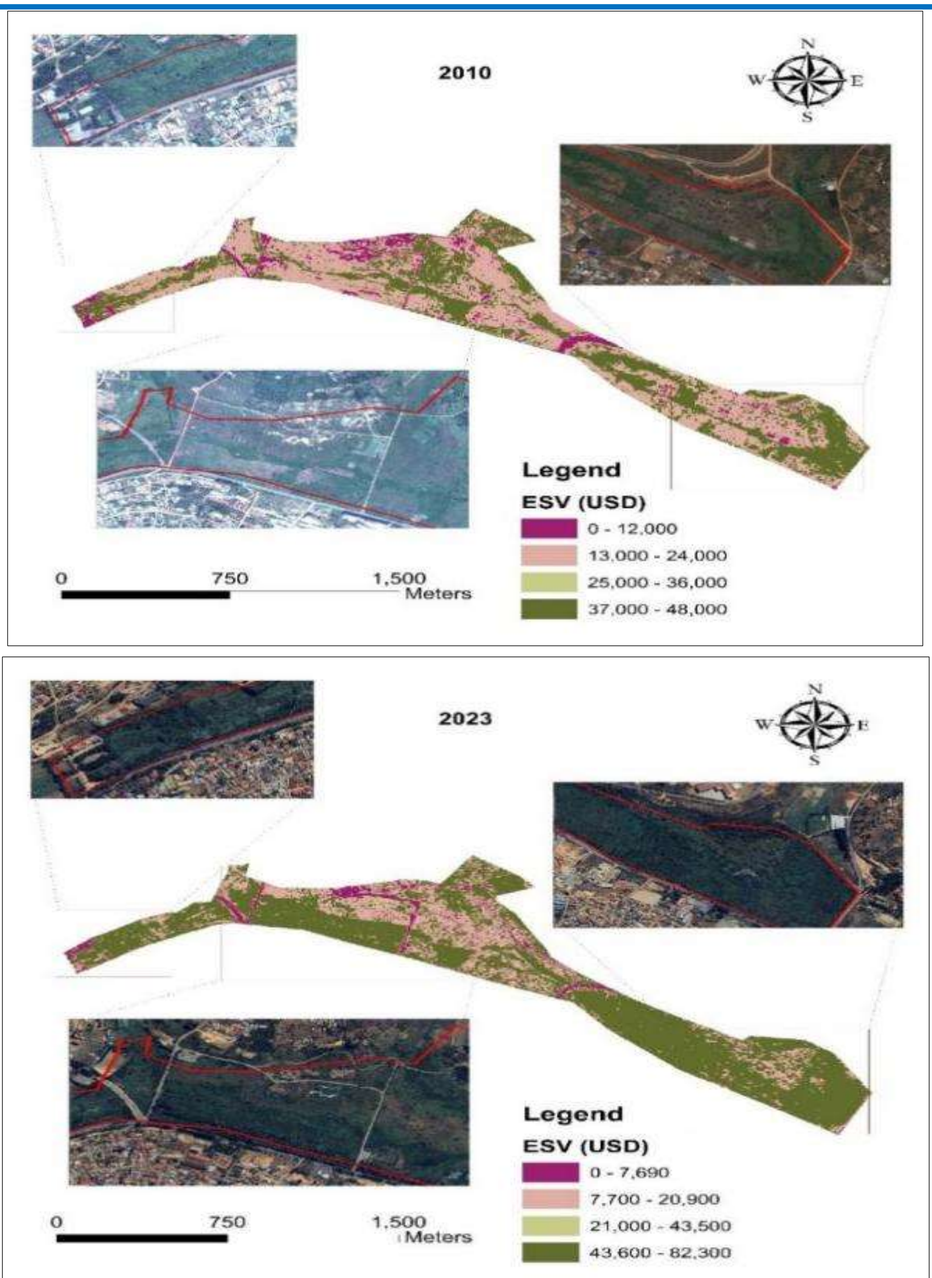

Fig 3.19: Temporal and spatial evolution of ESV before and after EBA interventions based on Kindu et al.(2016)

In 2010, the total ESV was $97,340.52/ha/year, with forests accounting for the largest value ($48,212.44/ha/year), followed by water ($31,273.03/ha/year). However, by 2023, the total ESV had increased to $127,820.19 per ha/year, indicating considerable improvements in ecosystem services, with Forests having the high value ($82,335.83/ha/year) followed by Water bodies with ($37,007.06/ha/year) and Built-up the last with zero value.

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 69-101 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

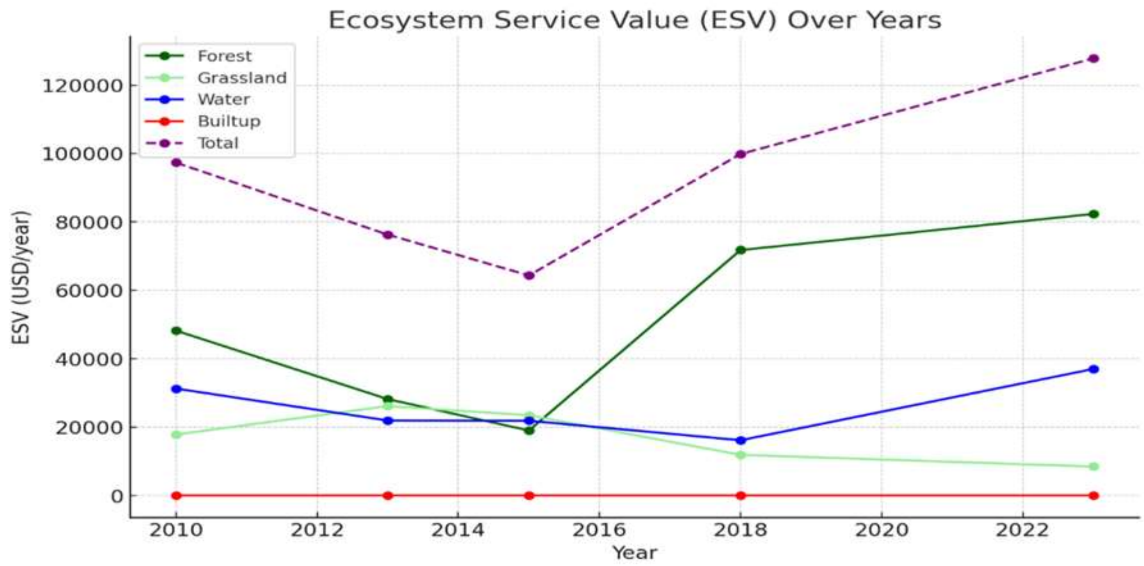

Fig 3.20: Ecosystem values trend (2010-2023).

The ESV of forests improved dramatically, more than doubling to $82,335.83/ha/year, illustrating the efficacy of restoration efforts such as the Nyandungu project in enhancing forest ecosystems. This increase was due to the efforts like the Nyandungu restoration project, which prioritizes the maintenance and repair of critical habitats to boost ecosystem resilience and improve ecological functioning (Nduwamungu, 2019).

Similarly, the water increased significantly, rising from $31,273.03/ha/year in 2010 to $37,007.06/ha/year by 2023. This positive trend indicates gains in water-related ecosystem services, which can be attributed to better water quality, better management methods, or conservation measures (REMA, 2023a). The increase in water is consistent with the Nyandungu project's concentration on wetlands conservation, demonstrating the favorable outcomes of targeted interventions in aquatic ecosystems. Both trends in forest and water demonstrate the efficacy of conservation and restoration efforts in increasing overall health and the value of essential ecosystems in the study area.

3.3.6. Overview of key interventions for flood risk reduction in Nyandungu wetland

To understand the benefits of established flood control benefits after Nyandungu wetland restoration the first step was to review the established interventions during the wetland restoration into park and their contribution to flood risk control. The literature review conducted revealed that during the restoration of Nyandungu wetland different interventions were established. Those intervention were established through established Sustainable Urban Drainage interventions and restoration of degraded vegetation using EbA interventions primarily for flood curbing (REMA, 2024). Those interventions include planted filtration Plants (vegetated swales or biofiltration basin), rehabilitated attenuation Ponds such as Pond Muhazi, Pond Kivu, Pond Ruhondo and Pond Ihema (REMA, 2024). Widened channels of Mwanana and Kabagenda River's to increase their capacity to transport water. Those interventions were restored to slow down the run off ,infiltrate and purify water in the wetland (Habakubaho, 2021; REMA, 2022c)

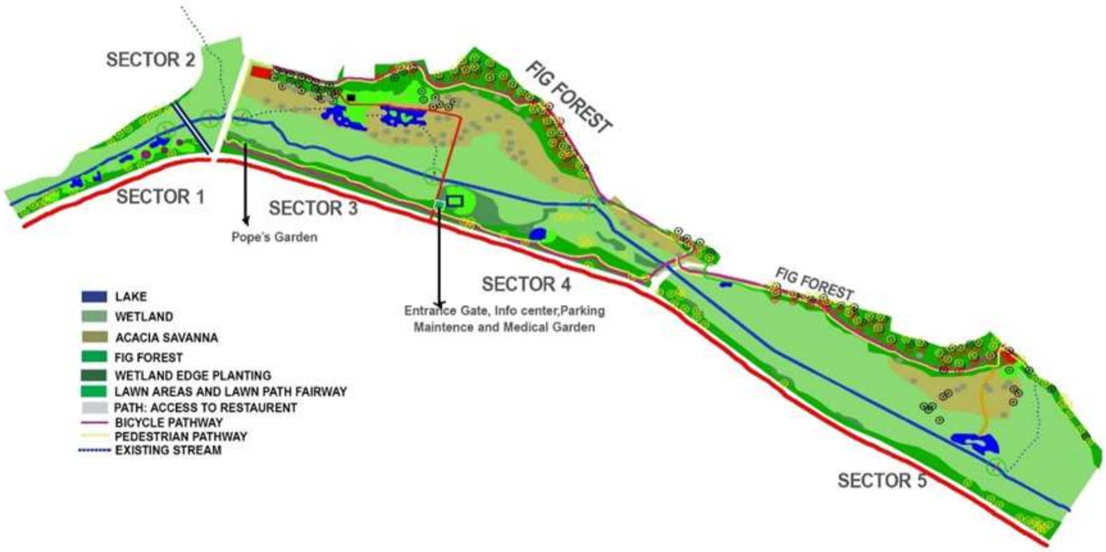

Fig.3.21: Interventions established in Nyandungu wetland restoration. Source: REMA, 2023.

As indicated in figure 13 above, the park was designed into five sectors (zones) which have different interventions. Sector one is comprised of filtration plants and actuation ponds. This sector is full of nature in terms of filtration plants and attenuation Ponds. Its main function is to reduce the speed of the water as it filters into the rest of the wetland. Sector two which is the smallest of all the sectors is comprised with filtration plants. It also has species of filtration plants to further slowdown and clean the water. Sector three which the Sector three is the center of the ecotourism activities in the park is comprised with walkaways and bicycle lane, pond Muhazi, pond Kivu, pope's garden, recreation area, and parking. Sector four is comprised with walkways and Bicycle lanes, medical gardens, pond Ruhondo and recreation area. The sector is a mix of light ecotourism activity as well as natural processes including filtration and slowing down of water. Last but not least, is the sector 5 is comprised with walkways and pond Ihema. Sector 5 which is the biggest of all sectors is the final processing point for the wetland. It hosts the Ihema pond Ihema and plenty natural forests and filtration plants (REMA, 2024).

3.3.7. Benefits of Nyandungu wetland restoration on flood risk reduction

Benefits of Nyandungu wetland restoration was analysed to assess the impact of the established interventions in reducing the flood risk and other associated impacts which have been affecting this wetland for a long time. Results from the conducted analysis are discussed below.

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 69-101 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

3.3.8. The contribution of each EbA intervention to LULC changes and TESV from 2010 to 2023

The Ecosystem Based Adaptation conducted at Nyandungu Wetland had the following objectives preserve the ecological function of the wetland, improve the air quality and other environmental health for surrounding community and Kigali city, represent the high-quality brand of Rwanda, provide space for education, recreation, and contemplation, cover its management costs (no need to generate revenue for other conservation areas), apply state of the art practices for environmental, economic, and social sustainability , support low impact amenities and activities benefits from these particular interventions at that site and that included reduced erosion and rainwater runoff, as well as increased water availability and the establishment of bio retention basins that provide waste treatment.

Table 3.14: The following are EbA interventions conducted at the Nyandungu wetland site and their corresponding benefits

Interventions	Primary Adaptation Benefits	Additional Adaptation Benefits	Co-Benefits
Establishing vegetated swales and check dams	Reduced erosion and rainwater runoff (erosion and flood control); increased water availability during variable rainfall	Hill stabilization; soil conservation; Maintained or enhanced agricultural productivity	Livestock fodder generation
Establishing bio-retention basins	Waste treatment and Manage stormwater runoff	Enhanced regulation of water flows, and improved access to water during low rainfall periods	Reduced incidence of disease
Planting trees and reforestation	Major increase of forested areas and corresponding decrease in grassland	Increased forest covers that help local climate and Soil stabilization with roots of trees	Improved green spaces enhance recreational opportunities and aesthetic appeal as well as the creation of habitats for various species.
Establishment of Catchment and Recreation Ponds	Creating catchment ponds and recreation ponds to manage water resources and support aquatic life.	Enhance infiltration and groundwater recharge, act as buffers during heavy rainfall, reducing the risk of flooding	Provide habitats for aquatic life and support biodiversity, offers spaces for recreational activities.

The transformative impact of Ecosystem-based Adaptation (EbA) on ecosystem services, specifically examining the elasticity of Land Use and Land Cover (LULC) changes in Ecosystem Service Value (ESV) across two periods before and after EbA activities, is detailed in Table 10.

Stratford Peer Reviewed Journals and Book Publishing
Journal of Agriculture & Environmental Sciences
Volume 9||Issue 2||Page 69-101 ||April||2025|
Email: info@stratfordjournals.org ISSN: 2616-8465

Table 3.15: Summary of ESV, WLCP, and EEL Before and After EbA Implementation

Period	ESV Start (USD/Year)	ESV End (USD/Year)	∆ ESV (USD/Year)	% Change In ESV	WLCP (%)	EEL
2010-2015 (Before EbA)	97,340.52	64,348.67	-32,991.85	-33.91%	9.98	-3.4
2018-2023 (After EbA)	99,853.27	127,820.19	27,966.92	28.04%	4.31	6.5

Before the introduction of Ecosystem-based Adaptation (EbA) from 2010 to 2015, there was a troubling decrease in Ecosystem Service Value (ESV) by approximately 33.91%. This time frame was characterized by a negative Elasticity of Ecosystem Service Value (Haase et al.) at -3.40, indicating that for every 1% change in Land Use and Land Cover (LULC), ESV decreased by 3.40%. This decline emphasizes significant environmental deterioration, likely caused by factors such as deforestation and grassland degradation. Despite a high Land Conversion Percentage (WLCP) of 9.98%, signifying substantial changes in LULC, the overall impact was negative, highlighting the harmful effects of unregulated land use practices on ecosystem services.

Following the implementation of EbA from 2018 to 2023, there was a noteworthy turnaround with ESV increasing by approximately 28.04%. This positive trend reflects the successful execution of EbA strategies, such as reforestation and ecosystem restoration efforts. The Elasticity of Ecosystem Service Value (Haase et al.) for this period was positive at 6.50, indicating that for every 1% change in LULC, ESV increased by 6.50%. This positive elasticity underscores the effectiveness of EbA in enhancing ecosystem resilience and service provision. Despite a moderate WLCP of 3.31%, which signifies moderate changes in LULC, the significant increase in ESV demonstrates that strategic conservation efforts can mitigate previous environmental degradation and contribute positively to ecosystem health and human well-being.

Comparing these two periods provides valuable insights into the transformative impact of EbA on ecosystem services. The negative trends observed before the introduction of EbA highlighted the urgent need for adaptive environmental management practices. In contrast, the positive outcomes after the introduction of EbA illustrate how targeted conservation and restoration initiatives can reverse environmental decline and promote sustainable resource management. These findings underscore the critical role of EbA in building ecosystem resilience to future environmental challenges, ensuring continued provision of vital services to local communities.

3. Conclusion

In conclusion, the assessment of Nature-Based Solutions (NbS) in Kigali demonstrated significant ecological improvements, with forest cover in Nyandungu Urban Wetland increasing from 49 to 83 hectares. Water-related areas also expanded due to the creation of ponds and ecotourism infrastructure. These changes led to a rise in the Total Ecosystem Service Value (ESV) from 97,340 to 127,820 USD per hectare per year, confirming the substantial environmental and socio-economic benefits of NbS interventions.

In analyzing the climate resilience status, the study found a major reduction in flood-prone areas, from 26 hectares in 2010 to just 2 hectares in 2023. Less flood-susceptible zones expanded, and indicators like NDVI and NDWI showed healthier vegetation and improved water content, highlighting how NbS interventions positively influenced flood management and ecosystem health.

The study established a strong relationship between NbS and climate resilience. Specific Ecosystem-based Adaptation (EbA) measures such as vegetated swales and check dams reduced erosion, increased water availability, and stabilized landscapes, resulting in enhanced biodiversity, improved livelihoods, and greater resilience against climate hazards in the urban setting. It is recommended to expand NbS interventions city-wide, integrate them into Kigali's urban development strategies, prioritize degraded wetland restoration, promote stakeholder collaboration, and invest in advanced valuation and hydrological modeling for better-informed, sustainable planning.

5. References

Acreman, M., & Holden, J. (2013). How wetlands affect floods. Wetlands, 33(5), 773–786. https://doi.org/10.1007/s13157-013-0473-2

Chang, X., Yu, L., Li, G., Li, X., & Bao, L. (2023). Wetland vegetation cover changes and its response to climate changes across Heilongjiang-Amur River Basin. Frontiers in Plant Science, 14, 1169898. https://doi.org/10.3389/fpls.2023.1169898

Dooley, W., & Stelk, M. (2021). Urban Wetlands Protection and Restoration Guide. Association of State Wetland Managers.

EPA. (2016). Wetlands: Protecting Life and Property from Flooding. 1–4. papers2://publication/uuid/47EE8A6A-8D9C-4115-AAAB-C812106F6D0D

EPA. (2022). Wetlands - Why are Wetlands Important? United States Environmental Protection Agency, 3–5. https://www.epa.gov/wetlands/why-are-wetlands-important

Fennessy, S. M., & Lei, G. (2018). Wetland Restoration for Climate Change Resilience. Ramsar, 1–11. https://www.ramsar.org/sites/default/files/documents/library/bn10_restoration_climate_change_e.pdf

Gakuba, A. (2012). Study for Establishing Urban Wetland Recreation and Eco-tourism Park in Nyandungu Valley, Kigali City (Rwanda).

GGGI. (2022). Sustainable Urban Wetlands Development within Kigali City- Nyandungu Wetland Eco-park. https://gggi.org/sustainable-urban-wetlands-development-within-kigali-city-nyandungu-wetland-eco-park/#:~:text=Wetlands in Kigali have been,promised to help them recover.

GoR. (2015). Constitution of the Republic of Rwanda of 2015. Official Gazette of the Republic, 24(December), 158. https://www.rwandabar.org.rw/attached_pdf/Constitution of the Republic of Rwanda-1608275353.pdf

GoR. (2016). National Biodiversity Strategy Plan. National Biodiversity Strategy and Action Plan, December.

Green, M. (2019). Water management for agriculture under a changing climate : case study of Nyagatare watershed in Rwanda climate. 1–67.

Habakubaho, T. (2021). Building the capacity of Rwanda's government to advance the national adaptation planning process: Feasibility Study.

Ingabire, M. C., Ntaganira, E., Mugorereyimana, V., Muzezayo, J. P., Nahayo, L., & Ngaboyamahina, T. (2020). Impact of Flood on Wetland Ecosystem Services in

Kindu, M., Schneider, T., Teketay, D., & Knoke, T. (2016). Changes of ecosystem service values in response to land use/land cover dynamics in Munessa-Shashemene landscape of the Ethiopian highlands. Science of the Total Environment, 547, 137–147. https://doi.org/10.1016/j.scitotenv.2015.12.127

KT Press Staff Writer. (2017). Wetland encroachers stand warned, prosecution is coming. https://www.ktpress.rw/2017/06/wetland-encroachers-stand-warned-prosecution-is-coming/

Kyanga, A. (2021). Consultancy services to conduct the baseline study for the project "building the capacity of Rwanda's government to advance the National Adaptation Planning process.

Li, Y., Zhaxi, D., Yuan, L., Li, A., Li, J., Wang, J., Liu, X., & Liu, Y. (2024). The Effects of Climate Change on the Distribution Pattern of Species Richness of Endemic Wetland Plants in the Qinghai-Tibet Plateau. Plants, 13(14). https://doi.org/10.3390/plants13141886

Lv, J., Jiang, W., Wang, W., Wu, Z., Liu, Y., Wang, X., & Li, Z. (2019). Wetland loss identification and evaluation based on landscape and remote sensing indices in Xiong'an new area. Remote Sensing, 11(23). https://doi.org/10.3390/rs11232834

Mind'je, R., Li, L., Amanambu, A. C., Nahayo, L., Nsengiyumva, J. B., Gasirabo, A., & Mindje, M. (2019). Flood susceptibility modeling and hazard perception in Rwanda. International Journal of Disaster Risk Reduction, 38(April), 101211. https://doi.org/10.1016/j.ijdrr.2019.101211

MINEMA. (2023). National disaster risk reduction and management policy. 1–53. https://www.minema.gov.rw/index.php?eID=dumpFile&t=f&f=70104&token=1e6bdd5b22ad6a5455e3c313753ea76b327568a3

Ming, J., Xian-guo, L., Lin-shu, X., Li-juan, C., & Shouzheng, T. (2007). Flood mitigation benefit of wetland soil — A case study in Momoge National Nature Reserve in China. Ecological Economics, 61(2), 217–223. https://doi.org/https://doi.org/10.1016/j.ecolecon.2006.10.019

Nduwamungu, J. (2019). Building resilience of communities living in degraded forests, savannahs and wetlands of Rwanda through an Ecosystem based Adaptation (EbA) approach project.

Nzuve, L. (2023). Urban wetlands restoration builds resilience and liveability. https://www.sei.org/perspectives/urban-wetlands-restoration-builds-resilience-and-liveability/#:~:text=Conserved and restored urban wetlands,weather impacts such as flooding.

Ramsar. (2022). Wetland city accreditation. https://www.ramsar.org/activity/wetland-city-accreditation

RAMSAR. (2017). Wetlands for disaster risk reduction: Effective choices for resilient communities. In Ramsar Convention.

RCMRD. (2022). Wetland Vulnerability Analysis (Issue 254).

REMA. (2013). Kigali State of Environment and Outlook Report 2013.

REMA. (2019a). Building resilience of communities living in degraded forests, savannahs and wetlands of Rwanda through an Ecosystem based Adaptation (EbA) approach project.

REMA. (2019b). Ecosystem-based Adaption guidelines for climate resilient restoration of savannahs, wetland and forest ecosystems of Rwanda. 102.

REMA. (2020). National wetlands management framework for Rwanda. December. https://www.rema.gov.rw/fileadmin/user_upload/National_Wetland_Management_Framework_Final_V2.pdf

REMA. (2021a). Building the capacity of Rwanda ' s government to advance the National Adaptation Planning Process Feasibility Study (Issue January).

REMA. (2021b). The Second Rwanda Urban Development Project (RUDP II). https://www.rema.gov.rw/our-work/projects/rudp-ii

REMA. (2022a). Building Capacity of Rwanda's Government to advance the national adaptation planning Process (NAP) Project.

REMA. (2022b). City of Kigali awarded wetland city accreditation. https://www.rema.gov.rw/info/details?tx_news_pi1%5Baction%5D=detail&tx_news_pi1%5Bcontroller%5D=News&tx_news_pi1%5Bnews%5D=650&cHash=025943939b1ecd73e2e749392bb67036

REMA. (2022c). Nyandungu Eco-Park Kigali, Rwanda-Conservation Area Business Plan. March. https://www.rema.gov.rw/home

REMA. (2022d). Nyandungu Urban Wetland Ecotourism. https://www.rema.gov.rw/our-work/projects/nyandungu-urban-wetland-ecotourism

REMA. (2022e). RUDP-II. https://www.rema.gov.rw/our-work/projects/rudp-ii

REMA. (2022f). Updated Feasibility Study for Establishing Nyandungu Urban Wetland. February.

REMA. (2023a). Request for Proposals Public Private Partnership (PPP) for the Management of Nyandungu Eco- Park (NEP) in the City of Kigali (Issue June).

REMA. (2023b). Rwandans urged to halt wetlands degradation and contribute to wetlands restoration. https://www.rema.gov.rw/info/details?tx_news_pi1%5B%40widget_0%5D%5BcurrentPage%5D=2&tx_news_pi1%5Baction%5D=detail&tx_news_pi1%5Bcontroller%5D=News&tx_news_pi1%5Bnews%5D=673&cHash=b7039f9473e37173253f64a7a5d7d34b

REMA. (2024). Nyandungu urban wetland eco-park Project compendium.

Rwanda Environment Management Authority. (2007). Pilot Integrated Ecosystem Assessment of Bugesera Table of Contents (Issue January). http://www.unpei.org/sites/default/files/PDF/Bugesera-Rwanda.pdf

Short, F. T., Kosten, S., Morgan, P. A., Malone, S., & Moore, G. E. (2016). Impacts of climate change on submerged and emergent wetland plants. Aquatic Botany, 135, 3–17. https://doi.org/https://doi.org/10.1016/j.aquabot.2016.06.006

Stratford, C. J., Acreman, M. C., & Rees, H. G. (2011). A simple method for assessing the vulnerability of wetland ecosystem services. Hydrological Sciences Journal, 56(8), 1485–1500. https://doi.org/10.1080/02626667.2011.630669

USEPA. (2000). Principles of Wetland Restoration. https://www.epa.gov/wetlands/principles-wetland-restoration

Verisk Maplecroft. (2014). Climate Change Vulnerability. January, 1–3. http://maplecroft.com/portfolio/new-analysis/2013/10/30/31-global-economic-output-forecast-face-high-or-extreme-climate-change-risks-2025-maplecroft-risk-atlas/

Were, D., Kansiime, F., Fetahi, T., Cooper, A., & Jjuuko, C. (2019). Carbon Sequestration by Wetlands: A Critical Review of Enhancement Measures for Climate Change Mitigation. Earth Systems and Environment, 3(2), 327–340. https://doi.org/10.1007/s41748-019-00094-0

Zhang, L., & Kondolf, G. M. (2024). Ponds and Wetlands Landscapes of Flood Management in the Cities of the Lower Yellow River Floodplain—The Case of Huaiyang, China. Water (Switzerland), 16(5). https://doi.org/10.3390/w16050703

Zhang, M., Zhang, D., Qi, Q., Tong, S., Wang, X., An, Y., & Lu, X. (2022). Flooding effects on population and growth characteristics of Bolboschoenus planiculmis in Momoge wetland, northeast China. Ecological Indicators, 137, 108730. https://doi.org/https://doi.org/10.1016/j.ecolind.2022.108730

Zhang, Y., Li, W., Sun, G., & King, J. S. (2019). Coastal wetland resilience to climate variability: A hydrologic perspective. Journal of Hydrology, 568, 275–284. https://doi.org/10.1016/j.jhydrol.2018.10.048