Rwanda Journal of Engineering, Science, Technology and Environment, Volume 7, Issue 1, March 2025
eISSN: 2617-233X | print ISSN: 2617-2321

Unveiling the Resilience of Unprotected Wetlands Through a Comprehensive Wetland Health Index Assessment, Rwanda: The Case of Kiyonga Wetland.

Mucyo Ndera Tuyizere.[1*], Nyandwi Elias[2], Ishimwe Axcel[3], Joel Ndayisaba[4]

[1] Climate Adaptation team, GanzAfrica, Kigali – Rwanda
[2] University of Rwanda, College of Sciences and Technology, Centre for Geographic Information Systems and Remote Sensing (CGIS - UR), P.O. Box: 3900 Kigali, Rwanda
[3]Ihelp Rwanda, Kigali – Rwanda
[4]Albertine Rift Conservation Society (ARCOS), Kigali – Rwanda.
*Correspondence: Mucyo Ndera Tuyizere. Email: mucyo.nderat@gmail.com,

Abstract

Wetlands are vital ecosystems providing numerous ecological services, yet they face increasing threats from anthropogenic activities and environmental changes. Thus, monitoring and evaluation of their status is crucial to ensure sustainable uses. This study focuses on assessing wetland health in Kigoya wetland located in the western province of Rwanda by employing the Wetland Health Index, a multivariable approach integrating Geographic Information Systems (GIS) and remote sensing by analyzing land use and land cover (LULC) spanning four decades (1990-2023). Moreover, a comprehensive Wetland Health Index was developed using Analytic Hierarchical Processes (AHP) amalgamating environmental and climatic factors to assess wetland resilience and vulnerabilities. Significant transformations in the wetland landscape were unveiled, including notable expansions of built-up areas and declines in bare land. Significant transformations in the wetland landscape were unveiled, due to dynamic conversion from natural conditions to man-made environment. Statistical analyses of the index revealed diverse wetland health statuses, with fair health comprising 76.89 Ha (45.35% of total area), good health covering 32.27 Ha (19.03%), poor health occupying 53.24 Ha (31.40%), and critical health encompassing 0.63 Ha (0.37%). These findings provide information on the status, health, and restoration potentials of Kigoya wetlands and similar ecosystems. The WHI index is useful for advocating for integrated conservation efforts to safeguard the wetland's ecological integrity and resilience.

Keywords: Wetland, Health Index, Resilience, Land Use, Land Cover, Analytic Hierarchical Processes.

1. Introduction

Wetlands are crucial ecosystems with diverse ecological, social, and economic significance (Janse et al. 2019; Xu et al. 2019). Wetlands support diverse life forms, regulate floods, filter water, and store carbon, benefiting both nature and humanity (Balwan and Kour 2021; Dawson and Martin 2015). Moreover, they provide recreational opportunities, sustenance, and cultural significance, contributing significantly to well-being and prosperity (Lynch, Kalumanga, and Ospina 2016; Pueyo-Ros, Ribas, and Fraguell 2019; Pukowiec-Kurda 2022).

According to the Recent Global Wetland Outlook Report 2021 (Convention on Wetlands, 2021), wetlands are still being lost at an alarming rate, with 35% lost globally since 1970. This makes wetlands our most threatened ecosystem, disappearing faster than other natural resources like forests, and complete disappearance is caused largely by land-use change, with agriculture being the biggest driver of degradation (Marianne Courouble et al.,2021). Climate impacts on wetlands are occurring faster than anticipated, with changes in hydrology being one of the key effects(Gardner, Okuno, and Pritchard 2023). Above all, wetlands are losing their ability to filter water and sequester carbon as effectively as before (Ferreira Et Al, 2023). Therefore, it is crucial

https://dx.doi.org/10.4314/rjeste.v7i1.13

to assess the health of wetlands to address a wide range of ecological, economic, social, and environmental challenges.

The Wetland Health Index (WHI) is a comprehensive tool used to evaluate the ecological condition of wetlands, defined as a composite measure assessing various aspects such as water quality, biodiversity, hydrology, and human impact (Yang et al. 2023). The WHI involves collecting and analyzing data on physical, chemical, and biological parameters, integrating them to provide an overall health score for the wetland(Vollmer et al. 2018). The use of GIS and remote sensing technologies facilitates efficient mapping and monitoring by providing crucial spatial and temporal data(Wu 2017). Spatial data help detect the status and changes in land use, vegetation cover, and water dynamics, essential for assessing wetland conditions(Yang et al. 2018). The WHI inform significantly conservation and management efforts, enabling stakeholders to make informed decisions to protect and restore wetlands.

In Rwanda, wetlands play a crucial role in both the ecological sustainability and socio-economic development of the country (Gaspard et al. 2022). Since joining the Ramsar Convention on 29 December 2003, Rwanda has committed to preserving its wetlands and ensuring their sustainable use. Significant progress has been made, including the inventory and classification of wetlands, as stipulated in the Prime Minister's Order No. 006/03 of 30 January 2017, which organizes wetlands based on soil type, vegetation, hydrology, and climate for optimized management and development(REMA 2023). The Ministry of Environment in 2022 highlights several achievements, such as the restoration of Nyandungu Eco-Park and the rehabilitation of other wetlands in Kigali, including Rugenge, Rwintare, and the lower Nyabugogo wetlands as part of the Rwanda Urban Development Project (RUDP II) (MoE 2022).

However, in 2022, the study conducted by the Nile Basin Initiative in 2020 showed that Rwanda's wetlands are being lost and degraded at a faster rate compared to any other ecosystems in the country (NBI, 2020). The rapid pace of urbanization, agricultural expansion, and industrialization has resulted in increased pressure on these delicate ecosystems(Bagstad et al. 2020; Mind'je, and Kayumba 2021). The country still faces a lot of pressure, especially with unsustainable agriculture practices, extraction of sand, and fabrication of construction bricks (Bikorimana, Maniraho, and Umuziranenge 2024; Uwimana et al. 2018). ARCOS's study in 2021 has shown that more than half of the wetlands in Rwanda are being used for agricultural activities and energy production(ARCOS 2021). Existing research in Rwanda has contributed to our understanding of wetland functions and their socio-economic implications. For instance, studies by Nsengimana et al. (2017) and Ntabakirabose et al. 2022) highlighted the significance of wetlands in water resource management and local livelihoods (Ntabakirabose et al. 2022; Nsengimana, Weihler, and Kaplin 2017). These studies underscore the critical need for effective wetland management to balance conservation goals with socio-economic demands. These studies highlight the urgent need for effective wetland management that balances conservation with socio-economic demands. However, a comprehensive assessment of wetland health particularly one that integrates geospatial technology to explore wetland resilience beyond the socio-economic perspective will largely contribute to the understanding of wetland's resilience in Rwanda.

Kigoya Wetland, located in Nyamasheke District, is ecologically important as it serves as the entry point for two main rivers which are Karundura and Kigoya rivers following towards Lake Kivu. In the past years, the wetland was with no human interaction, and water was present year-round, supporting native species. However, human activities such as agriculture and building expansion have increased pressure both within and around the wetland. This growing human interaction have led to the degradation of wetland which necessitates understanding of the current health status of the wetland to aid in the decision-making and management of this vital natural resource.

https://dx.doi.org/10.4314/rjeste.v7i1.13

This research endeavors to develop a comprehensive Wetland Health Index, which will consider ecological, climatic and hydrological factors. By mapping changes in land use and cover over the past few decades, we intend to offer a nuanced understanding of the human impacts to Kigoya wetland. This index will serve as a tool for integrating geospatial technology in evaluating wetland resilience and vulnerabilities, contributing to informed decision-making for sustainable wetland management in Rwanda and beyond.

2. Methodology

2.1. Study Area Description

Kigoya Wetland, situated within Rwanda's western province in Nyamasheke district, is positioned at coordinates 2°18'19" S and 29°08'30" E. This wetland covers an expansive area of 172 hectares. The wetland boasts a unique geography, being home to two prominent rivers: Kigoya and Karundura, both of which converge to discharge into the vast expanse of Lake Kivu. This geographical context amplifies the wetland's significance as a nexus of hydrological interactions.

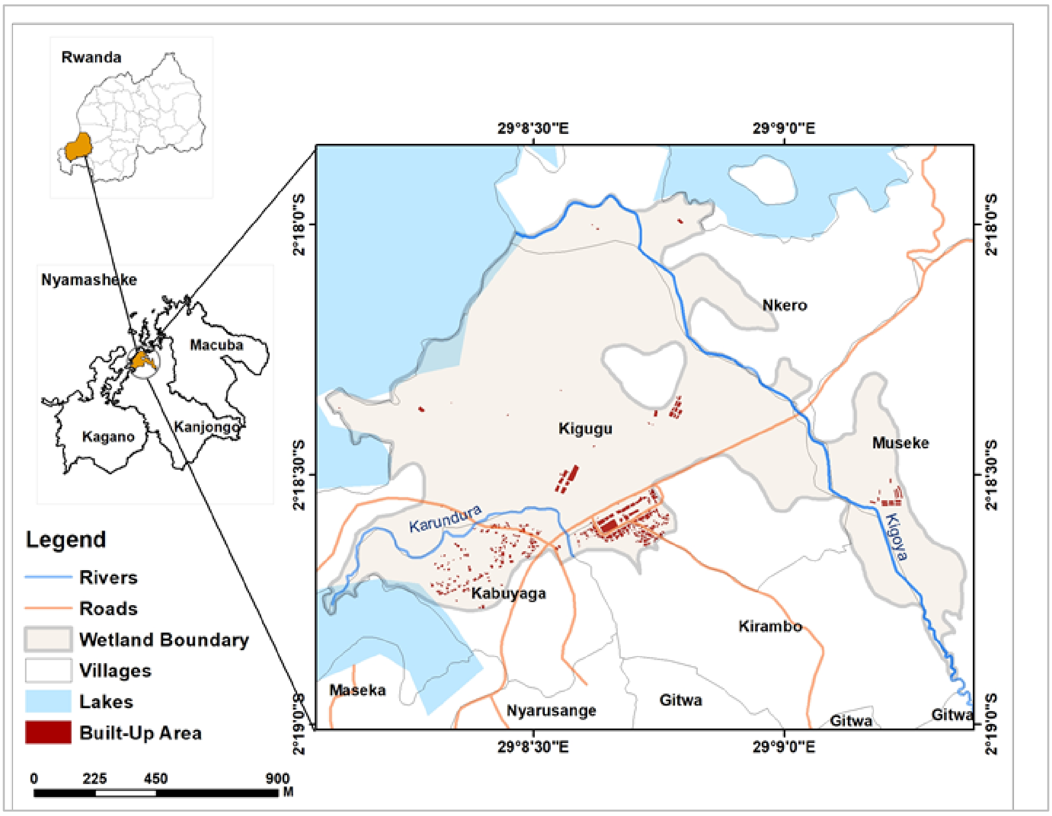

Figure 1: Study area

2.2. Data Sources / Acquisitions

Satellite imagery data utilized for examining the changes in land use and land cover over 33 years (1990-2023) within the Kigoya wetland encompassed four historical Landsat 5 and 7 images of 1990, 2000, and 2010 obtained from the Earth Explorer database of the United States Geological Survey (https://earthexplorer.usgs.gov/). The other sentinel 2 level A image for 2023 was downloaded from European sentinel browser (https://apps.sentinel-hub.com/eo-browser). Administrative boundaries, including shapefiles of roads and hydrological (rivers, and lakes) network were acquired from the Africa Geoportal powered by Esri. National wetland shapefile data acquired from Rwanda Spatial Data Hub (https://rwanda.africageoportal.com/) managed by

https://dx.doi.org/10.4314/rjeste.v7i1.13

National Land Authority. The digital elevation model (DEM) specific to Rwanda with 30m resolution was downloaded from the Regional Centre for Mapping of Resources for Development (RCMRD) open data site. The selection of datasets was guided by their temporal and spatial coverage, suitability for wetland studies, and ability to provide relevant information for LULC change detection. Landsat and Sentinel-2 imagery were chosen for their global availability, free access, and proven application in LULC studies. Administrative and hydrological shapefiles, along with the DEM, provided essential spatial context for the wetland. Finally, climatic data enabled an exploration of the role of environmental factors in driving observed changes. Google Earth Pro images from different years were used to support the validation of classification results.

Table 1: Satellite image sources: Name, Data acquisition, Bands, and Purposes.

Satellite and Sensor	Acquisition Date	Spatial Resolution (m)	Spectral Bands Used	Purpose
Landsat 5 TM	30 July 1990	30	Red, NIR, SWIR	Historical LULC analysis (1990)
Landsat 7 ETM+ C2 L2	15 June 2000	30	Red, NIR, SWIR	Decadal analysis (2000)
Landsat 7 ETM+ C2 L2	29 July 2010	30	Red, NIR, SWIR	Decadal analysis (2010)
Sentinel-2 MSI Level A	15 September 2023	10	Red, NIR, SWIR	Recent LULC analysis (2023)

Table 2: Climatic and Administrative source: Name of Dataset, Source, and Purpose.

Dataset	Source	Purpose
Administrative boundaries	Africa Geoportal and Rwanda Spatial Data Hub	Contextual mapping of roads and rivers.
Wetland shapefiles	Rwanda Spatial Data Hub	Delineation of the Kigoya Wetland.
Digital Elevation Model (DEM)	RCMRD Open Data Site	Analysis of topographical influences.
Climatic data (rainfall, temperature)	Meteo Rwanda	Evaluation of climate-driven impacts on the wetland's health.

2.3 Data Pre-processing

The multi-temporal satellite imagery and climatic datasets were preprocessed to ensure consistency in spatial and spectral characteristics, facilitating reliable comparisons between Landsat and Sentinel-2 imagery. Using ArcGIS Pro, the preprocessing involved several key steps:

(1) **Projection and coordinate system harmonization**: All images were re-projected to WGS 84, UTM Zone 35S to ensure spatial alignment.

(2) **Resampling**: The spatial resolution of all images was adjusted to 30 meters to match Landsat's coarsest resolution and all pixel depth were change to have 8 bit.

(3) **Band selection and compositing**: Comparable spectral bands (Red, Green, Blue, and Near Infrared) were composited into a unified dataset for each time period.

https://dx.doi.org/10.4314/rjeste.v7i1.13

(4) **Climatic data preprocessing**: Rainfall and temperature datasets were harmonized by projecting to the same coordinate reference system and ensuring consistent spatial resolution for seamless integration with satellite imagery.

These steps mitigated inherent differences between Landsat and Sentinel-2 sensors, enabling scientifically robust comparisons.

2.4 Data analysis techniques

2.4.1. Land Cover/Use Mapping

Following data preprocessing, the four images were subjected to supervised classification to analyze land use and land cover. The classification process encompassed five distinct and main land cover classes observed within the study area: water, built-up areas, bare land, grassland, and cropland.

Each class was selected to encapsulate the main land cover types present within the selected wetlands: The "*water*" class demarcates aquatic bodies, central to wetland ecosystems. "*Built-up* areas" represent human settlements and any building structures, serving as indicators of urban influence. "*Bare land*" highlights open soil areas, often indicative of exposed surfaces. "Grassland" captures the presence of natural or planted grassy expanses, while "*cropland*" signifies cultivated agricultural plots within the wetland vicinity. This classification was further validated through an accuracy assessment process using Kappa Coefficient metrics. Google Earth Pro images from different years were used as reference to create ground truth samples. An accuracy assessment was conducted to ascertain the classification outcomes' accuracy reliability. Subsequently, the classified land cover maps were used to detect the changes using overlayed images and were employed for change comparison analysis, unveiling significant land use and land cover changes over the study period. In addition, a field visit for wetland health outputs validation was done to check whether the results match with what is on the ground.

2.4.2. Wetland Health Index

a) Factors selection

To achieve an accurate evaluation of wetland status, the selection of pertinent indicators was very important. This investigation reviewed prior wetland research studies in the specific study area to identify the most crucial indicators. Subsequently, a method known as the Analytic Hierarchy Process (AHP) weighted overlay was employed to construct a Wetland Health Index (WHI). The AHP has been selected as one of the most widely used Multi-Criteria Assessment approaches, which allows users to assess the relative weight of multiple criteria or multiple options against given criteria in an intuitive manner (Taherdoost, 2017). This comprehensive index incorporates six factors: precipitation levels, land use and land cover patterns, temperature fluctuations, proximity to rivers (rivers), and two satellite image-derived metrics of plant health including the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Water Index (NDWI). These factors are categorized into environmental and climatic criteria as described in the table 3 below:

https://dx.doi.org/10.4314/rjeste.v7i1.13

Table 3:Factors for Generating Wetland Health Index

Factor	Descriptions
Precipitation	Annual precipitation was used in this research: Precipitation is a key factor in maintaining wetland hydrology (Bullock and Acreman 2003). It directly affects water levels, soil moisture, and the availability of water for plants and wildlife(Li et al. 2009). The long-term annual average amount of precipitation allows us to assess the water input to the wetland, which is crucial for its sustenance and ecological balance. High or consistent precipitation typically supports healthy wetland conditions, whereas low precipitation may indicate potential stress or drought conditions.
Temperature	Temperature impacts the metabolic rates of organisms, evaporation rates, and the overall thermal regime of the wetland(Kadlec and Reddy 2001). Extreme temperatures can stress both flora and fauna, potentially leading to shifts in species composition. The temperature helps in understanding the thermal conditions of the wetland, which affects species diversity, breeding cycles, and overall ecosystem resilience. Annual mean temperature was used in this case.
Proximity to river	Proximity to rivers influences water exchange, nutrient inflow, and sediment deposition in wetlands(Lane et al. 2018). Riverine wetlands often rely on periodic flooding for nutrient replenishment and habitat diversity. The distance from rivers can indicate the level of connectivity and the likelihood of regular water and nutrient influxes.
Land use/ Land cover	Land use and land cover around wetlands impact water quality, sediment load, and habitat integrity(Rooney et al. 2012). Urbanization, agriculture, and deforestation can lead to pollution, increased runoff, and habitat fragmentation. Analyzing land use and land cover provided insight into anthropogenic pressures on the wetland.
Normalized difference vegetation index	NDVI is used as an indicator of vegetation biomass and vigor, phenology, and productivity. NDVI can enhance the information on vegetation. The value of NDVI ranges from -1 to 1 where values lower than 0 represent high-reflection clouds and water bodies, while 0 indicates rocks and bare soils, positive NDVI values indicate areas with vegetation coverage, and the coverage positively increases with the value (Magney et al. 2016). NDVI is calculated as a ratio between the red and near-infrared (NIR) band values using the following equation: **NDVI = (NIR − Red) / (NIR + Red)** Where NIR is the near-infrared band spectral reflectance value and red corresponds to the reflectance in the red portion of the electromagnetic radiation spectrum.
Normalized difference wetness index	The normalized Difference Water Index (NDWI) was calculated for evaluating the wetness of the wetland (Özelkan 2020). NDWI was proposed by McFeeters (1996) as an indicator that can be applied for the evaluation of water content based on spectral data. NDWI is

https://dx.doi.org/10.4314/rjeste.v7i1.13

	calculated as a ratio between the green and near-infrared (NIR) band values using the following equation as demonstrated below: **NDWI = (Green − NIR) / (Green + NIR)** Green corresponds to the spectral reflection in the visible green portion of the electromagnetic radiation and (NIR) in the near-infrared portion of the EM spectrum.

b) Factors reclassification

Each of the six factors was reclassified into five suitability classes, with scores ranging from 5 (Very High Suitability) to 1 (Very Low Suitability) as shown in Table 4. This step ensured that all factors were standardized into a common scale for comparison and integration.

c) Comprehensive Wetland health index calculation

The Analytic Hierarchy Process (AHP) was utilized to develop a decision-making framework for evaluating the health of wetland ecosystems. AHP is a powerful tool for translating expert opinions, grounded in knowledge and experience, into a coherent decision-making structure(Hill et al. 2005; Saaty 1977). It offers a systematic and reliable method for capturing and quantifying subjective judgments (Malczewski and Rinner 2015). The hierarchy's top level represents the overall goal: assessing wetland ecosystem health. The second level includes the six indicators used in this study: precipitation, land use and land cover, temperature, proximity to rivers, normalized difference vegetation index, and normalized difference wetness index. The third level involves calculating the weights of these criteria using the equation (1).

The ecological health of wetlands in response to each indicator was assessed through theoretical analysis, literature review, prior knowledge, and practical experience. Given that each indicator has distinct measurement methods, we discussed each factor and assigned the weight accordingly.

d) Factors weighting

Key factors influencing wetland health were categorized into three domains: **ecological, hydrological, and climatic factors**. Each factor was reclassified into suitability classes and assigned a weight to reflect its relative importance in assessing wetland resilience. The **Analytic Hierarchy Process (AHP)** was employed to assign these weights systematically, based on expert judgment. A scale from 5 (most important) to 1 (least important) was used, and the weights were normalized to ensure their total equaled 1 (or 100%) as shown in the table below.

Table 4: Factor Weighting procedure: Factors, Domain, Reclassified, and weights given for each one.

Factor	**Domain**	**Reclassified Ranges**	**Weight (5–1)**	**Normalized Weight (%)**
NDVI	Ecological	0.183–0.731	5	30%
NDWI	Hydrological	0.016–0.688	4	25%
LULC	Ecological	Built-up, bare land, grassland, water bodies and perennial crop land.	5	30%
Proximity to river	Ecological	0–200 meters	3	15%

https://dx.doi.org/10.4314/rjeste.v7i1.13

Precipitation	Climatic	1,182.634–1,237.362 mm	2	10%
Temperature	Climatic	20.327–20.612°C	1	5%

e, Rationale for Weight Assignment

- **NDVI and LULC (5)**: Critical for assessing vegetation health and land use, directly influencing wetland functionality.
- **NDWI (4)**: Reflects hydrological conditions essential for resilience.

  Proximity to river (3): Moderately impacts accessibility and water resource availability.
- **Precipitation (2)** and **Temperature (1)**: Considered less critical due to lower variability in the study area.

The weighted factors were integrated through spatial overlay analysis in GIS to compute the **Wetland Health Index**, enabling a spatially explicit assessment of resilience across the Kiyonga wetland.

f) Weighted Overlay Calculation: The weighted overlay method follows a linear combination formula, where each reclassified factor's suitability score is multiplied by its corresponding weight. The results from all factors are then summed to generate a composite suitability index at each pixel. The mathematical formula for the weighted overlay method is:

SI = $\sum_{i=1}^{n} \boldsymbol{W_i} . \boldsymbol{X_i}$ **(n = 1, 2, . . . , 6) In this case, n=6** Equation (1)

where SI is the final suitability score at each pixel, $\boldsymbol{W_i}$ represents the weight of the ith factor, $\boldsymbol{X_i}$ is the reclassified suitability score of the ith factor, and n is the total number of factors, which in this case is 6 (Saaty, 1977). The resulting suitability score at each pixel represents a composite index that integrates the influence of all six factors, allowing for spatial identification of areas with varying suitability levels.

g) Composite Suitability Index: After applying the formula demonstrated in equation 1, the resulting suitability score for each pixel was classified into five categories: Excellent Health, Good Health, Fair Health, Poor Health, and Critical Health. This is a comprehensive index, where higher values (Excellent Health) indicate areas of greater suitability based on the combined influence of all factors. This index enables clear spatial differentiation of suitability levels across the study area.

3. Results and discussion

3.1. LULC Changes between 1990-2023

Over the course of four years, from 1990 to 2023, the land use and land cover dynamics of the studied area underwent significant shifts, as evident from the provided table, including net changes. Notably, the built-up area experienced a remarkable expansion, more than tripling from 1.71 Ha in 1990 to 15.53 Ha in 2023, indicating rapid urbanization or infrastructure development, with a net increase of 13.82 Ha. Conversely, bare land witnessed a considerable decline of 17.94 Ha, suggesting potential ecological transformations or land reclamation efforts. Cropland maintained a relatively stable area with a modest net increase of 10.51 Ha, indicating sustained agricultural activity despite other land use changes. The glass land category exhibited marginal fluctuations over the years, with a net increase of 1.24 Ha, possibly indicating stable land management practices or natural vegetation cover. However, the most significant shift occurred in the water body category, with a net decrease of 5.7 Ha from 2010 to 2023, suggesting potential environmental alterations, such as human intervention impacting water resources. These fluctuations underscore

https://dx.doi.org/10.4314/rjeste.v7i1.13

the complex interplay between human activities, environmental factors, and land management practices, highlighting the need for comprehensive monitoring and sustainable land use planning strategies to mitigate adverse impacts and promote ecological resilience in the wetland.

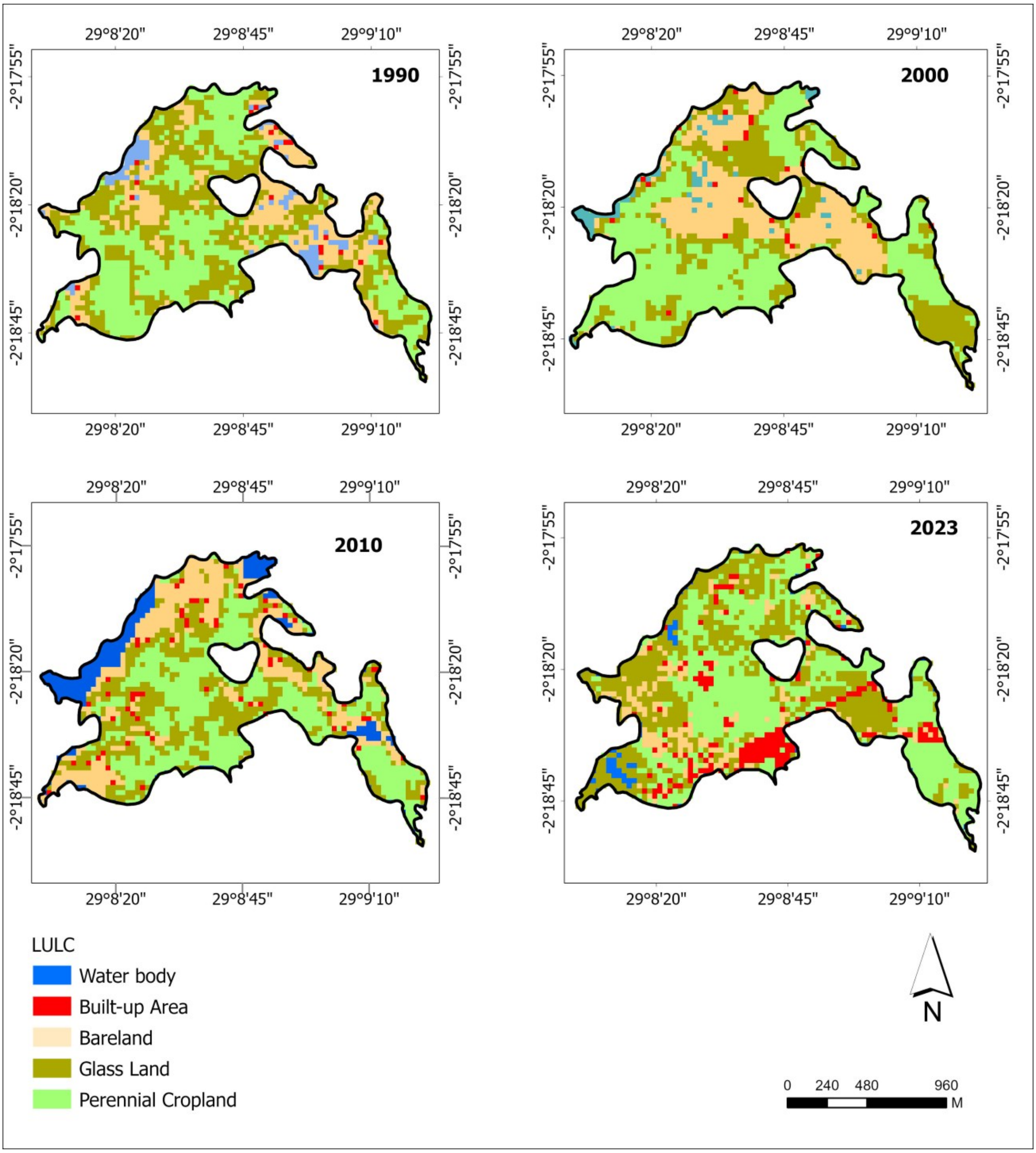

Figure 2: Land use Land cover maps from 1990 to 2023

https://dx.doi.org/10.4314/rjeste.v7i1.13

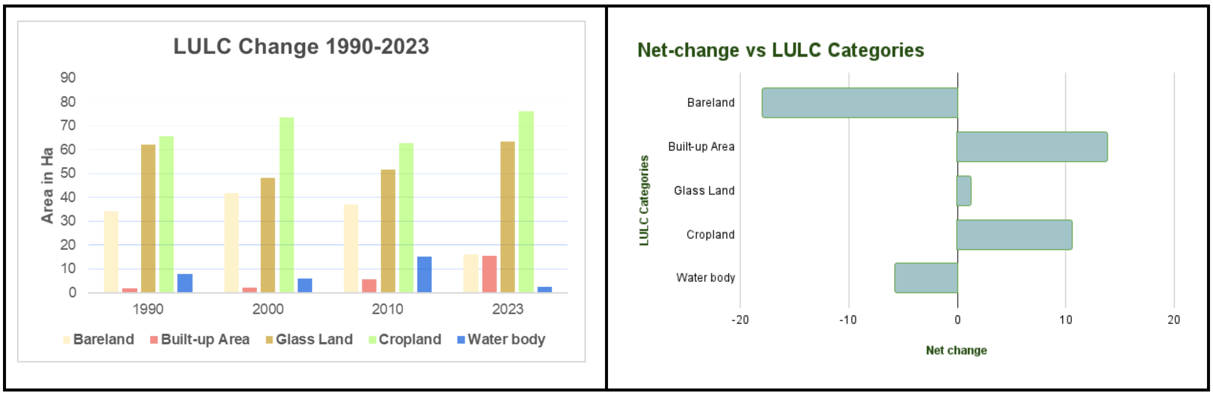

Figure 3: Graphs showing Land use land cover distribution over different years in hectares (left-side histogram) and the net change vs LULC Categories (right-side graph).

The accuracy of classified land cover/use maps was assessed using the overall accuracy matrix and Kappa coefficient. Overall accuracy ranges from 68.39% to 85.53%, indicating that a large proportion of the pixels were classified correctly while the Kappa coefficient ranges from 88.30% to 97.87%, indicating a high level of agreement between the classification result and the reference dataset while Kappa coefficients above 90% are generally considered to indicate excellent agreement (Warner, Nellis, and Foody 2009).

3.2. Wetland Health Index and Factors Contributing

3.2.1. Factors contributing to the wetland health index

To generate a comprehensive wetland health index, we combined several factors into distinct categories based on their characteristics. **Climatic factors** include **Precipitation** and **Temperature**, which influence water availability and ecosystem dynamics including plant health. **Land Cover and Land Use factors**, indicating the types and extent of land cover and utilization. **Hydrological Factors** consist of **Proximity to Rivers** and the **Normalized Difference Water Index (NDWI)**, assessing water sources' proximity and surface water content. Finally, **Vegetation Indices** include the **Normalized Difference Vegetation Index (NDVI)** for vegetation health and the **NDWI** for water content.

https://dx.doi.org/10.4314/rjeste.v7i1.13

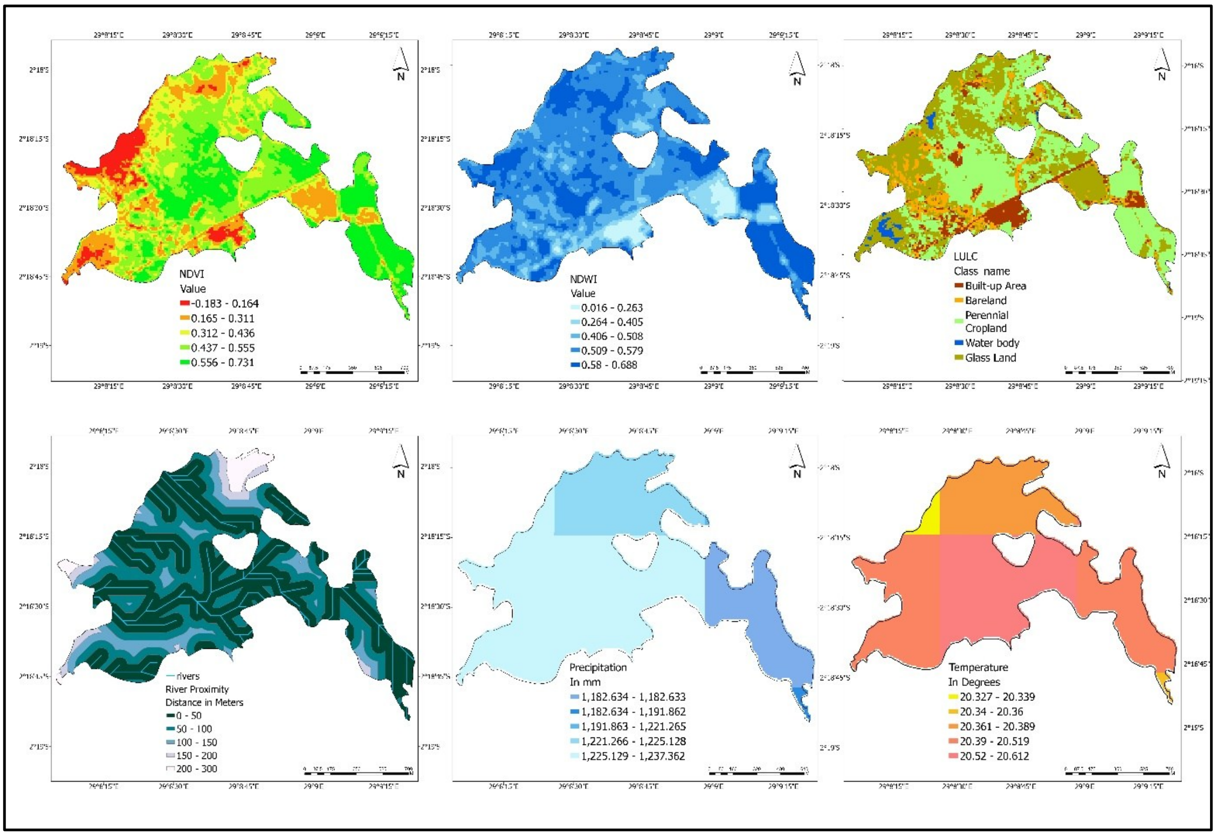

Figure 4: Maps of Factors contributing to the wetland health index: Precipitation, Land use/cover, Rainfall, Temperature, Proximity to the river, Normalized Difference Vegetation Index, and Normalized Difference Wetness Index.

3.2.2. Wetland Health Index

Notably, a significant portion of the wetlands, constituting 76.89 Ha or 45.35% of the total area, falls under the category of fair health, suggesting a relatively stable but potentially vulnerable ecological condition. Additionally, areas classified as being in good health encompass 32.27 Ha or 19.03% of the total area, indicating a substantial portion of the wetlands that are in relatively robust ecological condition. However, concerning is the presence of areas categorized as being in poor health, accounting for 53.24 Ha or 31.40% of the total area, indicating significant ecological stressors or degradation. Furthermore, the presence of areas classified as being in critical health, though constituting a small percentage of the total area (0.63 Ha or 0.37%), warrants immediate attention and intervention to prevent further deterioration.

https://dx.doi.org/10.4314/rjeste.v7i1.13

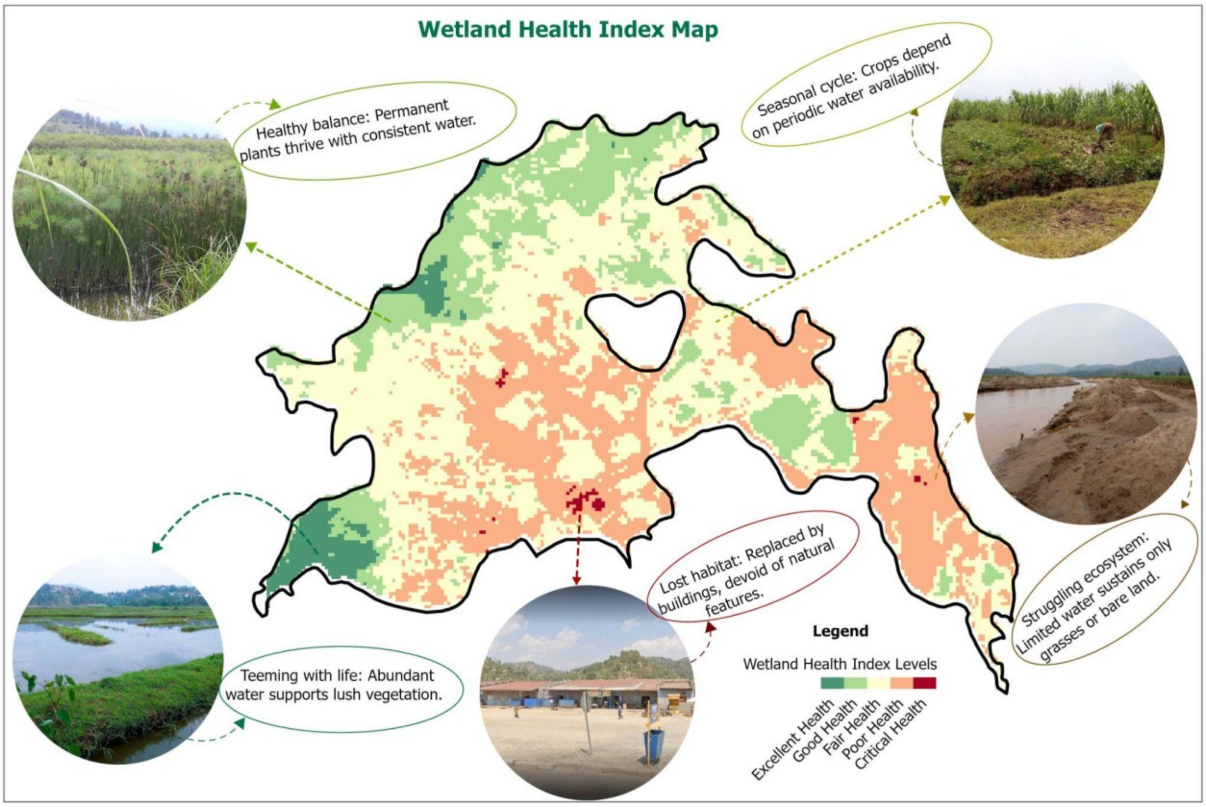

Figure 5: Generated Comprehensive Wetland Health Index with five classes: Excellent, Good, Fair, Poor, and Critical Health.

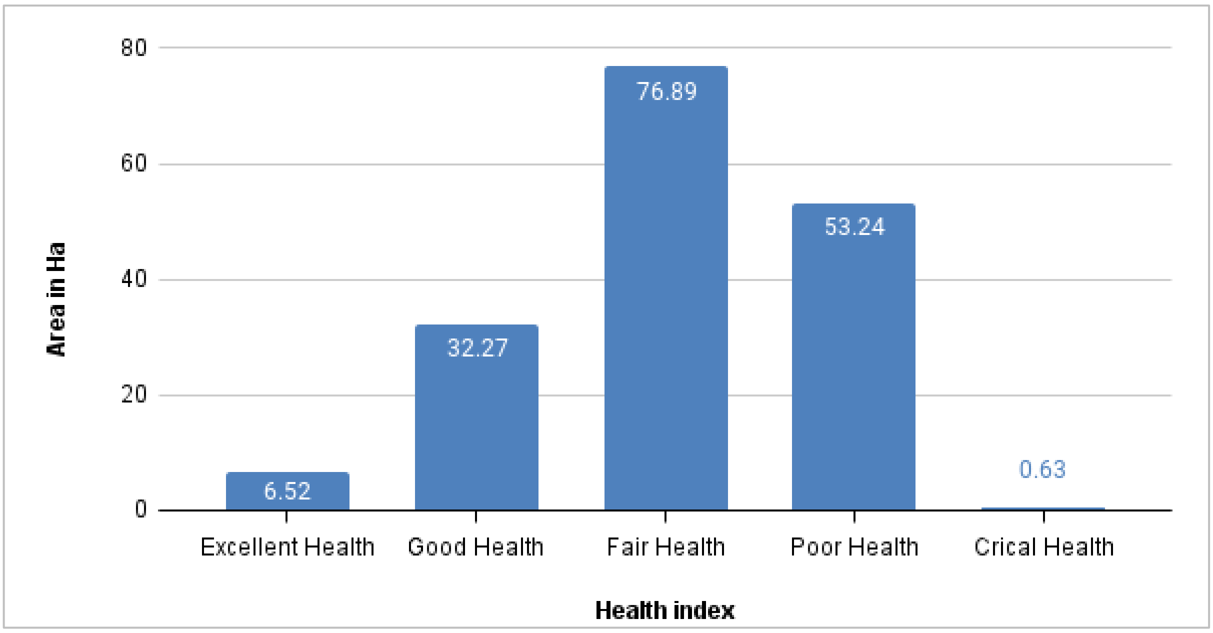

Figure 6: Comprehensive Wetland Health Index with five classes and the corresponding area in hectares

The largest portion of the wetland that falls under the category of fair health, suggests that while these areas maintain a stable ecological balance, they are still susceptible to potential threats. This stability is fragile and could easily tip towards degradation if not carefully managed and monitored. The relatively robust condition of areas in good health is encouraging, demonstrating that parts of the wetland are thriving and resilient, providing vital ecosystem services. However, this also underscores the need to understand the factors contributing to this good health to replicate these

https://dx.doi.org/10.4314/rjeste.v7i1.13

conditions in other areas. For the Kigoya wetland, the areas with good health area actually area covered by water and native species, especially along the lake's KIVU shorelines near to the lake where human interventions like agriculture and sand mining are still low.

The areas categorized as being in poor health reveal significant ecological stressors or degradation. These stressors stem from anthropogenic activities such as agriculture, urbanization, and pollution, which compromise the wetland's ability to provide essential services like water purification, flood control, and habitat for biodiversity. It is very clear for agriculture and bare soil within this wetland that plants and water are affected as a result of daily human activities. Addressing these issues will require targeted restoration efforts, reducing negative impacts, and enhancing the wetland's natural resilience.

The presence of areas in critical health, though small, is alarming. These critically impaired sections of the wetland are on the brink of collapse and require intensive intervention to prevent further degradation. Restoration efforts in these areas should focus on mitigating immediate threats, such as halting pollution sources, re-introducing native vegetation, and improving hydrological conditions. Ideally, the built-up expansion and existing industries within the wetland should be relocated to enhance the resilience of the wetland and reduce potential impacts they might create.

4. Conclusion

This research project has provided an understanding of the degradation and management needs of Kigoya Wetland. We used a combination of Geographic Information Systems (GIS) and remote sensing to analyze land use and land cover changes across four key years: 1990, 2000, 2010, and 2023. Our analysis revealed significant shifts, with built-up areas expanding and bare land shrinking. This highlights the growing human impact and environmental changes affecting the wetland. A key contribution of this research is the development of a comprehensive Wetland Health Index. This index combines environmental and climatic factors into a single framework for evaluating wetland health. Our analysis revealed a variation in health statuses, with "fair" health covering the largest area (45%), followed by "good" (19%), "poor" (31%), and a small portion in "critical" health (0.4%). Importantly, the index closely matched real-world data, demonstrating its reliability as a tool to support sustainable wetland management decisions. In conclusion, this research emphasizes the importance of data-driven decision-making for wetland management, relying on strong scientific methods and detailed spatial analysis. By exploring the complex relationship between human activities, environmental factors, and wetland health, this study lays the groundwork for adaptable management strategies specific to the Kigoya Wetland and similar ecosystems. The findings also have broader implications for wetland conservation and management efforts in Rwanda and worldwide, promoting integrated approaches that balance ecological needs with socio-economic considerations. Ultimately, this research serves as a call to action for collaborative efforts to protect the ecological health and resilience of wetlands, vital resources for biodiversity and ecosystem services in the face of growing environmental challenges.

5. References

1. ARCOS. 2021. "Albertine Lift Conservation Society(ARCOS), 2021. Rwanda Wetland Biodiversity Status Report."
2. Bagstad, Kenneth J., Jane Carter Ingram, Glenn-Marie Lange, Michel Masozera, Zachary H. Ancona, Mediatrice Bana, Desire Kagabo, Bernard Musana, Nsharwasi Leon Nabahungu, Emmanuel Rukundo, Evariste Rutebuka, Stephen Polasky, Denis Rugege, and Claudine Uwera. 2020. "Towards Ecosystem Accounts for Rwanda: Tracking 25 Years of Change in Flows and Potential Supply of Ecosystem Services" edited by Y. Buckley. *People and Nature* 2(1):163–88. doi: 10.1002/pan3.10062.

https://dx.doi.org/10.4314/rjeste.v7i1.13

3. Balwan, Wahied Khawar, and Sachdeep Kour. 2021. “Wetland- An Ecological Boon for the Environment.” *East African Scholars Journal of Agriculture and Life Sciences* 4(3):38–48. doi: 10.36349/easjals.2021.v04i03.001.
4. Bikorimana, Gerard, Leonidas Maniraho, and Gloriose Umuziranenge. 2024. “Exploring the Nexus between Natural Resource Management and Poverty Reduction in Rwanda.”
5. Bullock, A., and M. Acreman. 2003. “The Role of Wetlands in the Hydrological Cycle.” *Hydrology and Earth System Sciences* 7(3):358–89. doi: 10.5194/hess-7-358-2003.
6. Carla S.S. Ferreira, Milica Kašanin-Grubin, Marijana Kapović Solomun, Svetlana Sushkova, Tatiana Minkina, Wenwu Zhao, Zahra Kalantari, Wetlands as nature-based solutions for water management in different environments, Current Opinion in Environmental Science & Health, Volume 33, 2023, https://doi.org/10.1016/j.coesh.2023.100476.Convention on Wetlands. (2021). Global Wetland Outlook: Special Edition 2021. Gland, Switzerland: Secretariat of the Convention on Wetlands.
7. DNPWC and DFSC (2023). Wetland Health Report Card: A Methodological Framework for Assessing the Status of Wetlands in Nepal. Department of National Parks and Wildlife Conservation and Department of Forests and Soil Conservation. Ministry of Forest and Environment, Kathmandu, Nepal.
8. Dawson, Neil, and Adrian Martin. 2015. “Assessing the Contribution of Ecosystem Services to Human Wellbeing: A Disaggregated Study in Western Rwanda.” *Ecological Economics* 117:62–72. doi: 10.1016/j.ecolecon.2015.06.018.
9. Gardner, Royal C., Erin Okuno, and Dave Pritchard. 2023. “Ramsar Convention Governance and Processes at the International Level.” Pp. 37–67 in *Ramsar Wetlands*. Elsevier.
10. Gaspard, Ntabakirabose, Harold Ogwal, Jean Baptiste Habinshuti, Musoni Protais, Jeanne Pauline Munganyinka, David Mwehia Mburu, and Maniriho Festus. 2022. “Assessment of the Impact of Environment Protection in Rwanda: A Case Study of Rugezi Marshland.” *NASS Journal of Agricultural Sciences* 4(1). doi: 10.36956/njas.v4i1.464.
11. Hill, Michael J., Robert Braaten, Simon M. Veitch, Brian G. Lees, and Sunil Sharma. 2005. “Multi-Criteria Decision Analysis in Spatial Decision Support: The ASSESS Analytic Hierarchy Process and the Role of Quantitative Methods and Spatially Explicit Analysis.” *Environmental Modelling & Software* 20(7):955–76. doi: 10.1016/j.envsoft.2004.04.014.
12. Janse, Jan H., Anne A. Van Dam, Edwin M. A. Hes, Jeroen J. M. De Klein, C. Max Finlayson, Annette B. G. Janssen, Dianneke Van Wijk, Wolf M. Mooij, and Jos T. A. Verhoeven. 2019. “Towards a Global Model for Wetlands Ecosystem Services.” *Current Opinion in Environmental Sustainability* 36:11–19. doi: 10.1016/j.cosust.2018.09.002.
13. Kadlec, Robert H., and K. R. Reddy. 2001. “Temperature Effects in Treatment Wetlands.” *Water Environment Research* 73(5):543–57. doi: 10.2175/106143001X139614.
14. Lane, Charles R., Scott G. Leibowitz, Bradley C. Autrey, Stephen D. LeDuc, and Laurie C. Alexander. 2018. “Hydrological, Physical, and Chemical Functions and Connectivity of Non-Floodplain Wetlands to Downstream Waters: A Review.” *JAWRA Journal of the American Water Resources Association* 54(2):346–71. doi: 10.1111/1752-1688.12633.
15. Li, Sheng-nan, Gen-xu Wang, Wei Deng, Yuan-man Hu, and Wei-Wei Hu. 2009. “Influence of Hydrology Process on Wetland Landscape Pattern: A Case Study in the Yellow River Delta.” *Ecological Engineering* 35(12):1719–26. doi: 10.1016/j.ecoleng.2009.07.009.
16. Lynch, A. Jasmyn J., Elikana Kalumanga, and Guillermo A. Ospina. 2016. “Socio-Ecological Aspects of Sustaining Ramsar Wetlands in Three Biodiverse Developing Countries.” *Marine and Freshwater Research* 67(6):850. doi: 10.1071/MF15419.

https://dx.doi.org/10.4314/rjeste.v7i1.13

17. Magney, Troy S., Jan U. H. Eitel, David R. Huggins, and Lee A. Vierling. 2016. "Proximal NDVI Derived Phenology Improves In-Season Predictions of Wheat Quantity and Quality." *Agricultural and Forest Meteorology* 217:46–60. doi: 10.1016/j.agrformet.2015.11.009.
18. Malczewski, Jacek, and Claus Rinner. 2015. "Multicriteria Decision Analysis in Geographic Information Science." *Analysis Methods* (Massam 1993).
19. Marianne Courouble, Lars Dinesen, Siobhan Fennessy, Thomas Galewski, Anis Guelmami, Ritesh Kumar, Rob McInnes, Christian Perennou, Lisa-Maria Rebelo, Hugh Robertson, Lorena Segura-Champagnon, and Matthew Simpson & David Stroud. 2021. *Convention on Wetlands. (2021). Global Wetland Outlook: Special Edition 2021. Gland, Switzerland: Secretariat of the Convention on Wetlands.*
20. Mind'je, Richard, Mapendo Mindje, and Patient Mindje Kayumba. 2021. "The Influence of Anthropogenic Activities on Wetland Integrity Dynamics: A Case Study of the Rwampara Wetland in Rwanda." *Environmental Sustainability* 4(4):833–49. doi: 10.1007/s42398-021-00209-2.
21. MoE. 2022. *Ministry of Environment Annual Report 2021-2022*.
22. Nsengimana, Venuste, Simeon Weihler, and Beth A. Kaplin. 2017. "Perceptions of Local People on the Use of Nyabarongo River Wetland and Its Conservation in Rwanda." *Society & Natural Resources* 30(1):3–15. doi: 10.1080/08941920.2016.1209605.
23. Özelkan, Emre. 2020. "Water Body Detection Analysis Using NDWIIndices Derived from Landsat-8 OLI." *Polish Journal of Environmental Studies* 29(2):1759–69. doi: 10.15244/pjoes/110447.
24. Pueyo-Ros, Josep, Anna Ribas, and Rosa M. Fraguell. 2019. "A Cultural Approach to Wetlands Restoration to Assess Its Public Acceptance." *Restoration Ecology* 27(3):626–37. doi: 10.1111/rec.12896.
25. Pukowiec-Kurda, Katarzyna. 2022. "The Urban Ecosystem Services Index as a New Indicator for Sustainable Urban Planning and Human Well-Being in Cities." *Ecological Indicators* 144:109532. doi: 10.1016/j.ecolind.2022.109532.
26. REMA. 2023. "Rwanda Environmental Management Authority Yearly Quarterly News Letter 2023."
27. Rooney, Rebecca C., Suzanne E. Bayley, Irena F. Creed, and Matthew J. Wilson. 2012. "The Accuracy of Land Cover-Based Wetland Assessments Is Influenced by Landscape Extent." *Landscape Ecology* 27(9):1321–35. doi: 10.1007/s10980-012-9784-6.
28. Saaty, Thomas L. 1977. "A Scaling Method for Priorities in Hierarchical Structures." *Journal of Mathematical Psychology* 15(3):234–81. doi: https://doi.org/10.1016/0022-2496(77)90033-5.
29. Taherdoost, Hamed. (2017). Decision Making Using the Analytic Hierarchy Process (AHP); A Step by Step Approach. International Journal of Economics and Management Systems.
30. Uwimana, Abias, Anne A. Van Dam, Gretchen M. Gettel, and Kenneth Irvine. 2018. "Effects of Agricultural Land Use on Sediment and Nutrient Retention in Valley-Bottom Wetlands of Migina Catchment, Southern Rwanda." *Journal of Environmental Management* 219:103–14. doi: 10.1016/j.jenvman.2018.04.094.
31. Vollmer, Derek, Kashif Shaad, Nicholas J. Souter, Tracy Farrell, David Dudgeon, Caroline A. Sullivan, Isabelle Fauconnier, Glen M. MacDonald, Matthew P. McCartney, Alison G. Power, Amy McNally, Sandy J. Andelman, Timothy Capon, Naresh Devineni, Chusit Apirumanekul, Cho Nam Ng, M. Rebecca Shaw, Raymond Yu Wang, Chengguang Lai, Zhaoli Wang, and Helen M. Regan. 2018. "Integrating the Social, Hydrological and Ecological Dimensions of Freshwater Health: The Freshwater Health Index." *Science of The Total Environment* 627:304–13. doi: 10.1016/j.scitotenv.2018.01.040.

https://dx.doi.org/10.4314/rjeste.v7i1.13

32. Warner, Timothy A., M. Duane Nellis, and Giles M. Foody. 2009. *The SAGE Handbook of Remote Sensing*. 1 Oliver's Yard, 55 City Road London EC1Y 1SP: SAGE Publications, Inc.
33. Wu, Qiusheng. 2017. "GIS and Remote Sensing Applications in Wetland Mapping and Monitoring."
34. WWF. 2020. *Living Planet Report. Bending The Curve of Biodiversity Loss.* World Wildlife Fund.
35. Xu, Ting, Baisha Weng, Denghua Yan, Kun Wang, Xiangnan Li, Wuxia Bi, Meng Li, Xiangjun Cheng, and Yinxue Liu. 2019. "Wetlands of International Importance: Status, Threats, and Future Protection." *International Journal of Environmental Research and Public Health* 16(10):1818. doi: 10.3390/ijerph16101818.
36. Yang, Wenjing, Qinghui You, Na Fang, Liting Xu, Yi Zhou, Nanxi Wu, Caiying Ni, Ying Liu, Guihua Liu, Tao Yang, and Yeqiao Wang. 2018. "Assessment of Wetland Health Status of Poyang Lake Using Vegetation-Based Indices of Biotic Integrity." *Ecological Indicators* 90:79–89. doi: 10.1016/j.ecolind.2017.12.056.
37. Yang, Wenjing, Jie Zhong, Ying Xia, Qiwu Hu, Chaoyang Fang, Mingyang Cong, Bo Yao, and Qinghui You. 2023. "A Comprehensive Multi-Metric Index for Health Assessment of the Poyang Lake Wetland." *Remote Sensing* 15(16):4061. doi: 10.3390/rs15164061.

https://dx.doi.org/10.4314/rjeste.v7i1.13