Influence of Spatio-Temporal Changes of Nyando Wetland on Watershed Stakeholders' Perceptions on Its Sustainable Management

Janet A. Auma[1]*, Humphreys W. Obulinji[2] & Kennedy N. Ondimu[3]

[1]*Egerton University, Kenya (atieno.3000816@student.egerton.ac.ke)*

[2]*Egerton University, Kenya (humphreys.obulinji@egerton.ac.ke)*

[3]*Egerton University, Kenya (kondimu@egerton.ac.ke)*

**Corresponding author: atieno.3000816@student.egerton.ac.ke*

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Abstract

Nyando Wetland provides the watershed community with a range of interrelated environmental functions and socio-economic benefits that support a variety of livelihood opportunities. Threats from overuse and unsustainable management due to the adoption of a top-down approach interfere with the ecological functions of the wetland, resulting in spatio-temporal changes. This raises concerns about watershed stakeholders' perceptions in the management process. This paper employs a mixed research design to investigate the influence of spatio-temporal changes on watershed stakeholders' perceptions of sustainable management of Nyando Wetland. This will inform policy for the adoption of management options that involve stakeholders from the grassroots (Bottom-up approach). The target population of the study constituted 384 household heads, 45 heads of institutions, and 5 experts in wetland conservation and management. A simple random sampling technique was used to select 384 household heads at the household level. Purposive sampling was also used to select 45 heads of institutions and 5 experts for key informant interviews. Questionnaires, key informant interviews, focus group discussions, and direct observation were used to collect primary data. Remote sensing imagery was used to collect secondary data. Cross-tabulation and chi-square were used to analyze data. Results show a general decline in the Nyando Wetland area of 2269 ha (-27%) between the years 1992 and 2022. Further, stakeholders have divergent perceptions on sustainable management. Also, an increase or decrease in wetland area directly influences perceptions of sustainable management. Therefore, stakeholder participation should be fostered in decision-making. This will aid in the sustainable management of wetlands where participatory and conservation strategies align ecological restoration with the socio-economic needs of the watershed community. The paper recommends the restoration of the lost Nyando Wetland area through participatory wetland rehabilitation.

Keywords: Spatio-Temporal, Watershed, Stakeholders, Perceptions and Sustainable Management

Introduction

Wetlands are ranked among very diverse ecosystems that cover a proportion of about 4–6% of the land surface and provide an array of ecosystem services, which are categorized as provisioning, regulating, and cultural services (Gxokwe *et al*., 2020). Currently, wetlands are part of the agricultural system – they provide water for crops, livestock and aquaculture, habitat for rice production and pond fisheries, and help to regulate the environment (Ramsar Convention on Wetlands, 2022). Notwithstanding their critical importance, wetlands are increasingly being lost to rapid urbanization (Oduro *et al.,* 2024). Climate change and global rapid agricultural expansion have drastically reduced the area of wetlands globally recently, so that the ecosystem functions of wetlands have been impacted severely (Zhang *et al*., 2020). According to Garadew *et al*. (2023), wetland changes are primarily driven by farmland expansion, overgrazing, sedimentation, and climate variability. In addition, overuse and unsustainable management also contribute to wetland changes and loss.

According to Dalu *et al.* (2022), wetlands worldwide continue to be degraded due to unsustainable use and improper resource management. Unsustainable management exposes wetlands to negative impacts, which include the loss of wetland area, changes to the water regime and quality, introduction of alien species, and overexploitation of resources. About 64% of the world's wetlands have been lost since 1900 (Oduro *et al*., 2024 & Abdenour *et al*., 2025). In Africa, a large number of wetlands are thought to have been heavily modified by over-exploitation, and some have been lost, for instance, Yala Swamp and Kingwal wetland in Kenya; Nakivubo swamps in Uganda, Hadejia Jam' in Nigeria; and Ga-mampa swamp in South Africa (Garba *et al*., 2025). In Kenya, between 1970 and 2003, the area under swamps declined by about 40%; the flow rates (discharge) in most rivers reduced by 30%, and lakes have experienced dramatic fluctuations in water levels, with frequent dry outs, as has been the case for most of the Rift Valley Lakes (Aron Kecha *et al*., 2016).

The Nyando Wetland, which is the second-largest lacustrine wetland ecosystem on the Kenyan shores of Lake Victoria, is also facing rapid degradation. Yet, it provides the community with a range of inter-related environmental and socio-economic benefits that support a variety of livelihood opportunities (Maithya, 2021 & Raburu, 2015). The threat from overuse and over-exploitation, lack of application of new management technologies, and weak institutional policies has resulted in a reduction of the biodiversity within the wetland (Maithya, 2021). Further, the wetland ecological functions have been interfered with, resulting in spatio-temporal changes. A study by Okotto-Okotto (2016) showed an increasing trend for small-scale agriculture (+58 ha/yr) against a decreasing trend for water area (-29 ha/yr). This depicts a decrease in area, as revealed by Okotto-Okotto (2016) and Okotto-Okotto *et al*. (2018); the Nyando Wetland area decreased by 31% between 1984 and 2010. Maithya (2021) also found that Nyando Wetland was reduced by -2,933.1 Ha (-24.4%) between 1985 and 2020. This confirms a paradigm shift in Nyando Wetland utilization, meaning that the wetland has become part of social and economic development that should be sustainably used. Therefore, the wetland requires frequent monitoring and evaluation using Remote Sensing (RS) and Geographical Information Systems (GIS) to ascertain the extent of spatio-temporal change.

In addition, the sustainability of the wetland is critically influenced by the perceptions of the watershed stakeholders. According to Basu *et al*. (2024), sustainable development strategies consult and incorporate the perceptions of local community wetland management groups. This requires an understanding of the perspectives of watershed stakeholders on the various watershed challenges and their perceived management routes (Onyango & Opiyo, 2021). Nelson *et al.* (2017) added that understanding the opinions and attitudes of farmers and other wetland users regarding wetland policies and regulations helps managers and policymakers in making informed decisions for sustainable wetland management. Different stakeholder perceptions affect the way they interpret the ecosystem services that are provided by the wetlands (Kadoma *et al*., 2023). Besides, positive perception and attitude towards wetland values and conservation are essential to the sustainable management and wise use of resources (Truong, 2021 & Sinthumule, 2021). Conversely, inadequate community participation, adoption of a top-down management approach, and poor institutional collaboration have led to limited success in the management of Nyando Wetland. Therefore, achieving social, economic and environmental sustainability in Nyando wetland calls for the inclusion of watershed stakeholders' perceptions in the management process. As such, understanding the nexus between the spatio-temporal changes and watershed stakeholders' perceptions is essential since the spatio-temporal changes influence stakeholder perceptions in sustainable management.

This paper presents empirical evidence on how spatio-temporal changes of Nyando Wetland influence watershed stakeholders' perceptions of its sustainable management, which is critical for policy in the management options that should involve stakeholders at the grassroots (Bottom-up approach). This will aid in the sustainable management of wetlands where participatory and conservation strategies align ecological restoration with the socio-economic needs of the watershed community.

Study Area

Nyando Wetland (Figure 1) is the second largest lacustrine wetland ecosystem on the Kenyan shores of Lake Victoria, after Yala Swamp, with a population of around 947,250 people (Kenya National Bureau of Statistics (KNBS), 2019). It covers an area of 42.79 km^2 within the Winam Gulf of Lake Victoria in East Africa (Ministry of Environment and Mineral Resources (MEMR, 2012 & Ongoro, 2017). It is located between $0^0 11'$ to $0^0 19'$S and $34^0 47'$ to $34^0 57'$E (Nile Basin Initiative, 2022) at the mouth of the Nyando River on the north-eastern shores of Lake Victoria. It lies between 1300 and 1000 meters above sea level, with an average elevation of 1134m (Onyango *et al*., 2022). The annual rainfall received is between 1000 and 1600 mm with a mean of 1184 mm and an estimated mean temperature of 23˚C (Rongoei & Tole, 2019; & van Dam *et al*., 2019). The long rains are received between March and May, while short rains occur in October and December (Rongoei & Tole, 2019). The soils of Nyando Wetland are mainly alluvium formed by large quantities of silt and sand (van Dam *et al*., 2019). The wetland is dominated by papyrus vegetation with patches of other emergent macrophytes such as Vossia cuspidata, Typha sp., Ipomoea aquatica, and Phragmites sp (Rongoei & Outa, 2016).

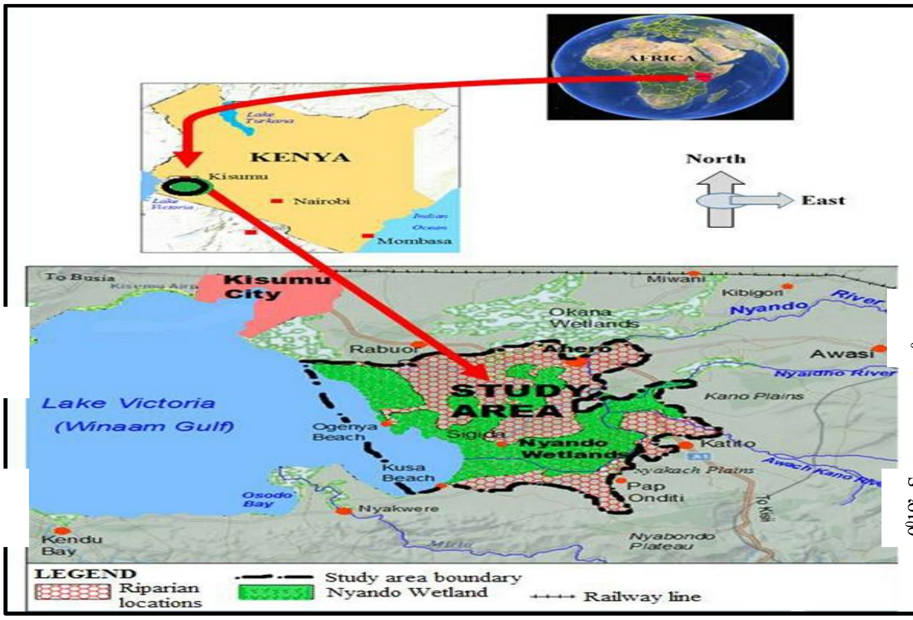

Figure 1: Map of the Study Area

Source: Modified from VIRED International (2019)

Administratively, the wetland is part of Nyando, Nyakach, and Kisumu East Sub-counties in Kisumu County. It borders Lower Nyakach, Nyando, Kadibo, and Winam Divisions. The wetland has numerous resources which support important economic and ecological activities (Maithya *et al*. 2022; & Latema 2020). Hence, it provides many functions and services to the environment and the local community. The Luo community living around the wetland practices various socio-economic activities, which include fishing, animal husbandry, mat-making, and cultivation of crops, among others (Rongoei & Kariuki, 2019). The main crops under cultivation include sugarcane, rice, maize and vegetables (Adunde *et al*., 2023).

The area was purposively selected as the study location since the wetland is the second largest after Yala Swamp on the shores of Lake Victoria, which provides numerous ecological and economic services to the environment and the local community. Hydro-ecological conditions of the Nyando area also expose the wetland to intensified anthropogenic activities such as farming, settlement, biomass harvesting, development of industries and urban centres, and grazing, especially during dry seasons. These activities may expose the wetland to degradation if not carried out wisely. There is a dire need for social, economic, and ecological sustainability for continued service provision and livelihood sustenance.

Methodology

The study employed a mixed research design to address the study problem. Both qualitative and quantitative data were used. The study used questionnaires, Key Informant Interviews (KIIs), Focus Group Discussions (FGDs), direct observation, and Remote Sensing (RS) to collect data. A mixed research design was used to allow the researcher to combine qualitative and quantitative approaches for the broad purposes of breadth and depth of understanding and corroboration. A simple random sampling technique was used to select 384 household heads at the household level. Fifty (50) Key Informants were also purposively selected. Their selection was based on proximity to the wetland, benefits they get from the wetland, activities they carry

0°19' S

out in the wetland, and their knowledge of environmental conservation and management. Therefore, the respondents included 384 household heads for questionnaire administration, 45 institutional heads and 5 experts for KII, and 20 participants for FGD.

Data was collected from both primary and secondary sources. Primary data were collected from the field using the following tools: questionnaires, KII schedule, FDG guide questions, and observation schedule. Secondary data was collected from journal articles, reports and relevant published books by carrying out a literature review on studies already done about the spatio-temporal changes and stakeholders' perceptions on sustainable management of wetlands. Data on spatio-temporal changes in wetland coverage for the last 30 years (1992-2022) were gathered from satellite images of Nyando Wetland. The images were downloaded from the United States Geological Survey for further analysis in Geographic Information Systems. The results of the study by Feng *et al.* (2019) suggested that a 30-year period in the future is most suitable to project the urban growth scenarios, where the new urban area approximates the initial urban area. A thirty-year period is long enough to experience a decrease or increase in wetland area.

Nyando Wetland boundary was used as the study area. The study area polygon was used to select cloud-free images and appropriate off-nadir angle of inclination, and date of acquisition from the United States Geological Surveys (USGS) glovis website (https://glovis.usgs.gov/). The LANDSAT imagery used covered a period of 10-year intervals starting in 1994 and ending in 2023 for the wet seasons. The satellite images described in Table 1 were utilized in the study. They included Landsat Thematic Mapper (TM) at 30 meter resolution, Aster at 15 meter resolution, and the Sentinel images at 10 meter resolution.

Table 1: Selected Satellite Images for Spatio-temporal Change Analysis

Satellite Sensor	Acquisition Dates	Resolution (meters)	Website search ID
TM	Oct 1994	30m	LT05_L1TP_170060_19941008_20200913
AST	Dec 2003	15m	ASTB 12010308123
AST	Jan 2012	15m	ASTB031212081341
Sentinel	Jan 2022	10m	T36MXE_20220126T075211

TM = Thematic Mapper sensor; AST =Aster and Sentinel
Source: Author (2024)

The images were subjected to both supervised and unsupervised classification for the spectral signature of features in order to distinguish various classes such as closed forest, open forest, highly degraded areas, and shrub land (Table 2). Ground-truthing to validate information gathered from satellite images was carried out. The classified raster and vector data were exported to the Geographical Information System (GIS) software ArcGIS 10. x for analysis and map design. GIS maps were produced to show the change in land cover area for the period from 1994 to 2022.

Table 2: Selected Satellite Images for Spatio-temporal Change Analysis

Cover class	Description
Forests Area (FA)	The continuous stand of trees, many of which may attain a height of 50 m, includes natural forests, mangrove, and plantation forest.
Grass/Shrub (G/S)	Areas of land covered with scattered grasses, shrubs
Grass/Bare (G/B)	Areas with exposed soil and rock outcrops with pits of scattered grass.
Reeds/Papyrus(R/P) Water areas (WA)	Areas covered by reeds and papyrus vegetation Areas naturally or artificially covered by water, shallow or deep.

Source: Author (2024)

The data gathered was analyzed quantitatively using both descriptive and inferential statistics. Frequencies, percentages, and chi-square were used. Chi-square test of independence was carried out to investigate the relationship between the change in wetland area 1992-2022 and stakeholders' perceptions on sustainable management indicators (quality of life, income level, availability of plant biomass, availability of animals and birds, soil and water conservation, and waste management).

Results

Spatio-temporal Changes of Nyando Wetland

Aerial images of Nyando Wetland were used to gather information on spatio-temporal changes from 1992 to 2022, where five cover type classes were identified, namely: shrub land, reeds/papyrus, grassland, farmland/bare areas, and water body. The cover type classes represented the entire wetland area, including converted areas. The current wetland area is represented by shrubland, reeds/papyrus, and a water body. Farmland/bare area and grassland represent converted areas. Within the converted area, there are settlements, crops, planted vegetation, especially eucalyptus, as was seen through observation. The initial intention was to use a 10-year interval (1992, 2002, 2012, and 2022), but this did not work in all cases due to clouding in 1992 and 2002 and water recession. Even though the 10-year interval was not used in all cases, the spatio-temporal changes were still mapped. Landsat TM (Landsat 5) (Figure 2) at 30m resolution of the year 1994, ASTER satellite imagery at 15m resolution of 2003 (Figure 3) and 2012 (Figure 4), and Sentinel (Figure 5) at 10m resolution of the year 2022 were used.

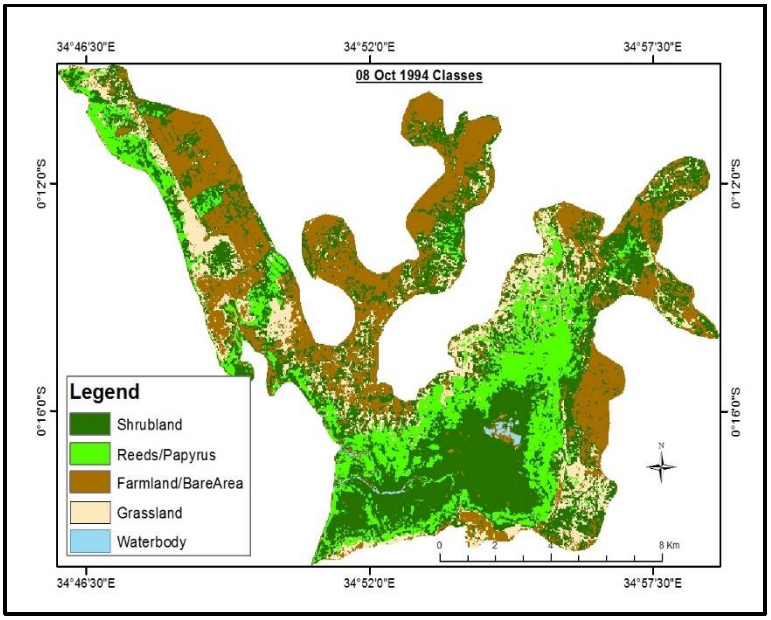

Figure 2: Landsat TM (Landsat 5) of 1994
Source: ArcGIS 10x (2024)

In 1994 (Figure 2), shrub land covered the largest area (5758ha) (Table 3) while water body covered the smallest area (68ha). Reeds/papyrus, grassland, and farmland/bare area covered 2563 ha, 1900 ha, and 4171 ha, respectively. In the year 2003 (Figure 3), farmland/bare area was the largest (6224ha) (Table 3). The area increased by 2053ha between the years 1994 and 2003 with an annual rate of 288ha/yr (Table 4). This means that more area was converted for cultivation and settlement as compared to the year 1994 and earlier. This depicted poorer wetland governance than in earlier years, when farming activities, settlement, harvesting of reeds/papyrus, uprooting papyrus roots for firewood, clearing of bushes, and burning were controlled, as was reiterated by FGD participants. Water body area remained the smallest (138ha) with an annual rate of 8ha/yr. Even though it was the smallest, it increased by 70ha. Shrub land (3725ha) and Reeds/papyrus (8141ha) decreased by 2033ha and 722 ha respectively, and grassland area (2492ha) increased by 592ha (Tables 3 and 4). Their annual rates of change were -226ha/yr, -80ha/yr and 66ha/yr respectively (Table 4). Shrubland was the most decreased area, implying that more areas were converted for cultivation, settlement, and grazing. Reduction in reeds/papyrus area might have been due to overharvesting, burning, and uprooting papyrus roots for firewood.

Table 3: Temporal Changes in Land Use Types (1994 – 2022)

Class Type	Class Type Coverage (Ha)			
	1994	2003	2012	2022
Shrub land	5758	3725	3262	3254
Reeds/Papyrus	2563	1841	2867	2866
Grassland	1900	2492	2442	2529
Farmland/Bare Areas	4171	6224	6242	5818
Water body	68	138	23	165
Total Area	14460	14420	14836	14467

Source: ArcGIS 10x (2024)

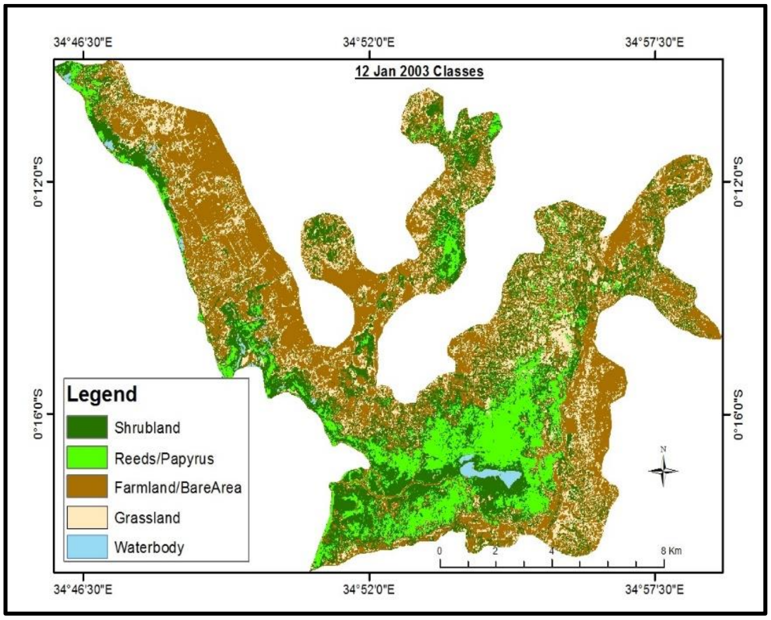

Figure 3: ASTER Satellite Imagery of 2003
Source: ArcGIS 10x (2024)

Farmland/Bare area further increased by 18ha with an annual rate of 2ha/yr between the year 2003 and 2012 (Table 4), and it remained the largest (6242ha) (Figure 4 and Table 3). Reeds/Papyrus area (2867ha) also increased by 1026 ha at an annual rate of 144ha/yr. Shrub land (3262ha), grassland (2492ha), and water body (23ha) decreased by 463ha, 50 ha, and 115 ha with an annual rate of -51ha/yr, -6ha/yr, and -13ha/yr, respectively. This shows further conversion of shrubland, grassland, and water body areas for crop farming and tree growing, as was witnessed through observation. In addition, reeds/papyrus might have regenerated, hence an increase in area.

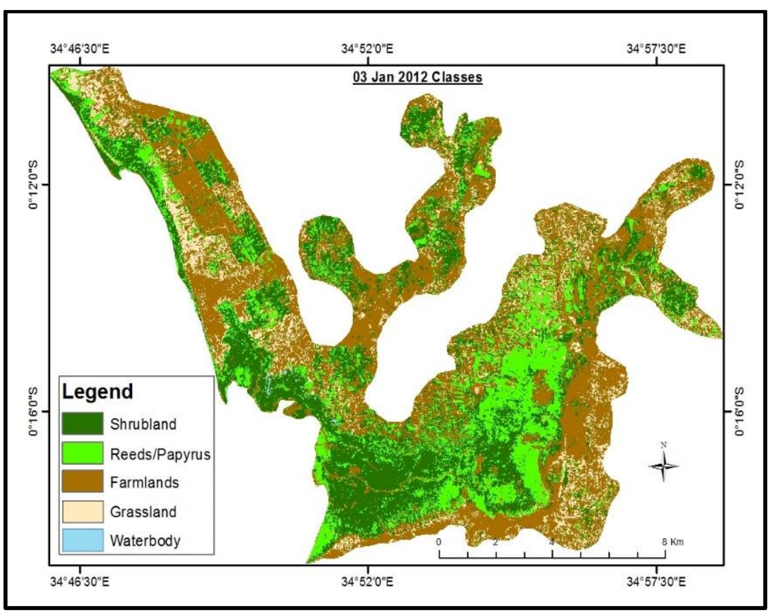

Figure 4: ASTER Satellite Imagery of 2012
Source: ArcGIS 10x (2024)

In 2022 (Figure 5), farmland/bare area covered 5818ha (Table 3). It decreased by 424ha between the years 2012 and 2022, with an annual rate of -42ha/yr even though it was the largest class type in the year 2022. Water body area (165ha) increased by 142ha with an annual rate of 14ha/yr (Table 4). This might have resulted from flooding from the River Nyando and backflow from Lake Victoria due to high rainfall received during this period. As a result, wetland cultivation might have declined with more cultivation activities carried out away from the wetland, hence a reduction in farmland/bare area. Shrub land area decreased by 8ha to 3254ha at an annual rate of -0.8ha/yr (Tables 3 and 4). More shrub land might have been converted to grassland landward for grazing, which led to an increase in grassland area by 87ha to 2529ha with an annual rate of 8ha/yr. Fluctuations in total class type coverage (Table 3) might have resulted from lake water recession, which increased the area between the year 2003 and 2012 by 416ha and back flow, which reduced the area between the year 1994 and 2003, and 2012 and 2022 by 40ha and 369ha respectively.

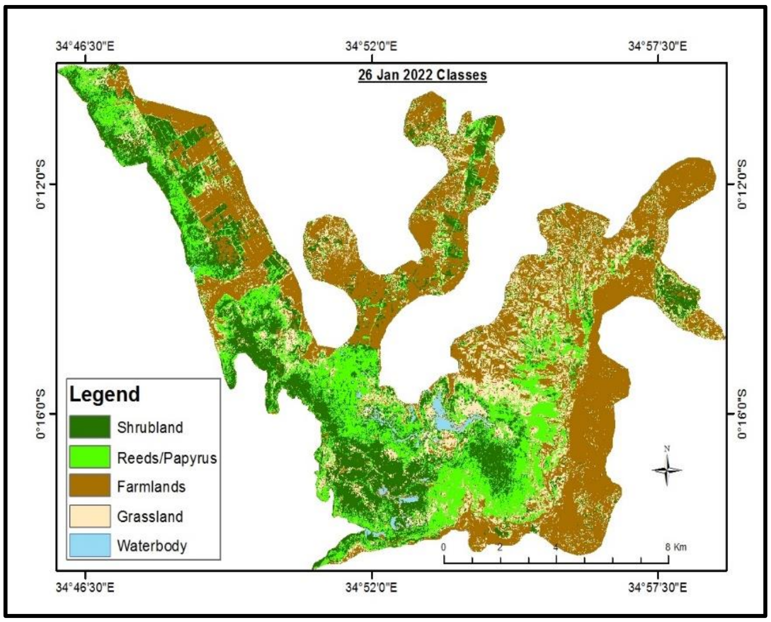

Figure 5: Sentinel Satellite Imagery of 2022
Source: ArcGIS 10x (2024)

Table 4: Overall Temporal Changes in Land Use Types (1994 – 2022)

Class type	Size in ha in 1994	1994-2003 (9 yrs) change in ha	Annual rate of change ha/yr	Size in ha in 2003	2003-2012 (9yrs) change in ha	Annual rate of change in ha/yr	Size in ha 2012	2012-2022 (10 yrs) change in ha	Annual rate of change in ha/yr
Shrub land	5758	-2033	-226	3725	-463	-51	3262	8	-0.8
Reeds/Papyrus	2563	-722	-80	1841	1026	114	2867	-1	0.1
Grassland	1900	592	66	2492	-50	-6	2442	87	8.7
Farmland/Bare	4171	2053	288	6224	18	2	6242	-424	42
Waterbody	68	70	8	138	-115	-13	23	142	14

Source: ArcGIS 10x (2024)

The trend in change in area (Figure 6) shows either an increase or a decrease in the area covered by each class type. This influenced a change in the entire wetland area due to the conversion of part of the wetland into farmland/bare areas, and grassland. The wetland area covered 8389ha in 1994 (Figure 7). The area decreased by 2685ha to 5704ha in 2003, increased by 448ha to 6152ha in 2012, and decreased by 32 ha to 6120ha in 2022 (Table 5). This might have been due to changes in climatic conditions, which caused flooding or drought, hence influencing the anthropogenic activities carried out in the wetland, such as cultivation, grazing, and harvesting of papyrus, among others, and natural processes such as plant biomass regeneration and wetland management strategies in place. Generally, the Nyando Wetland area declined by 2269ha (-27%) between the years 1994 and 2022.

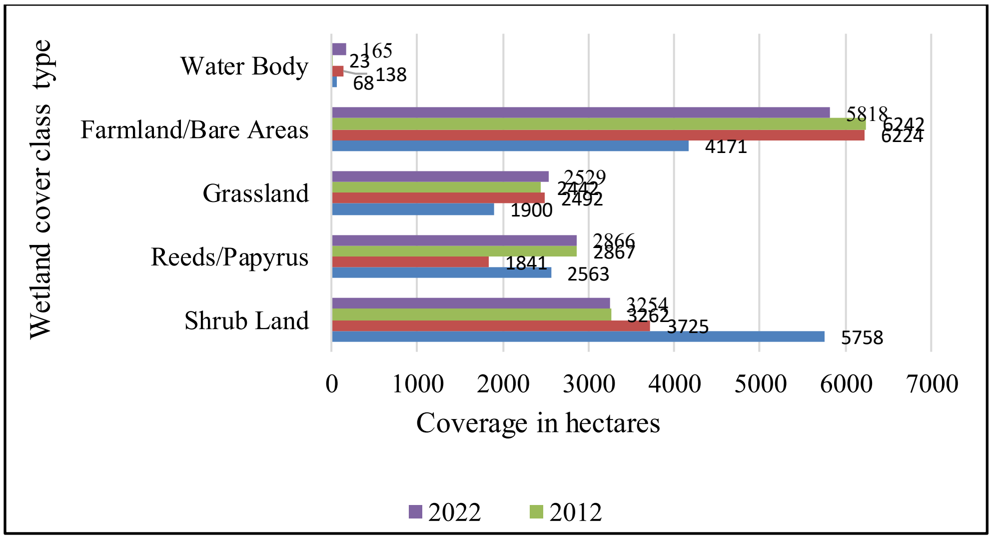

Figure 6: Change in Nyando Wetland Class Type in Hectares (1994 - 2022)
Source: Field Survey (2024)

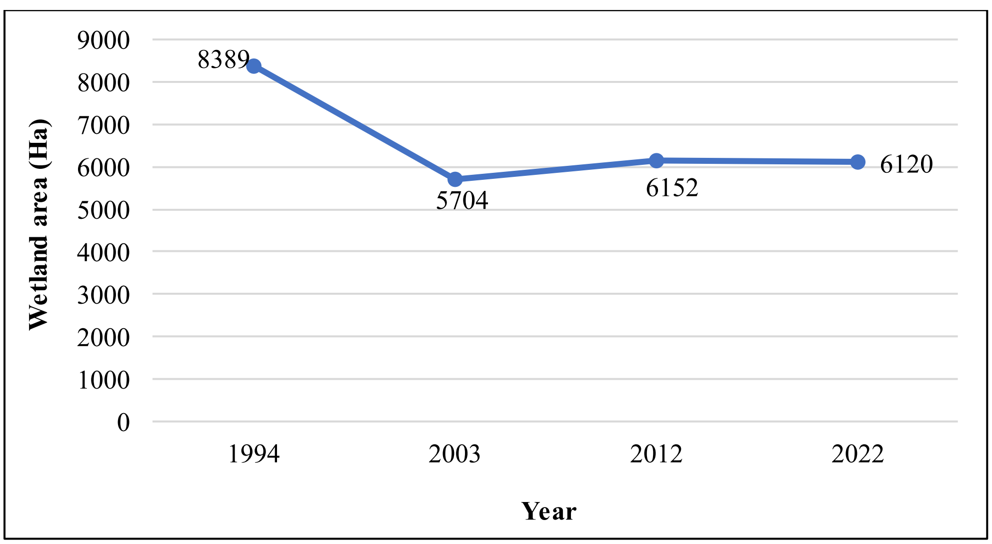

Figure 7: Trend in
Survey (2024) ***Change in Wetland Area from 1994 to 2022***
Source: Field

Table 5: Change in Wetland Area Between 1994 and 2022

Years	Change in wetland area		
	Hectares	Percent	Trend
1994-2003	-2685	-32	Decreased
2003-2012	448	8	Increased
2012-2022	-32	-0.5	Decreased

Source: Field Survey (2024)

Fifty-point eight percent (50.8%) (Figure 8) of the households indicated that the wetland area increased, while 46.6% indicated a decrease for a period between 1992 and 2002. In the second phase (2002-2012), 46.4% indicated that the area decreased, while 39.3% indicated that the area increased. During the last phase (2012-2022), 54.2% indicated that the area increased, while 43.5% indicated a decrease. Two-point six percent (2.6%), 14.3%, and 2.3%, respectively, indicated that the area remained the same between 1992 and 2022. Key Informant Interview (KII) and FGD results show that the wetland area has either shown a decreasing or an increasing trend based on prevailing climatic conditions, human activities carried out in the wetland, and resource governance.

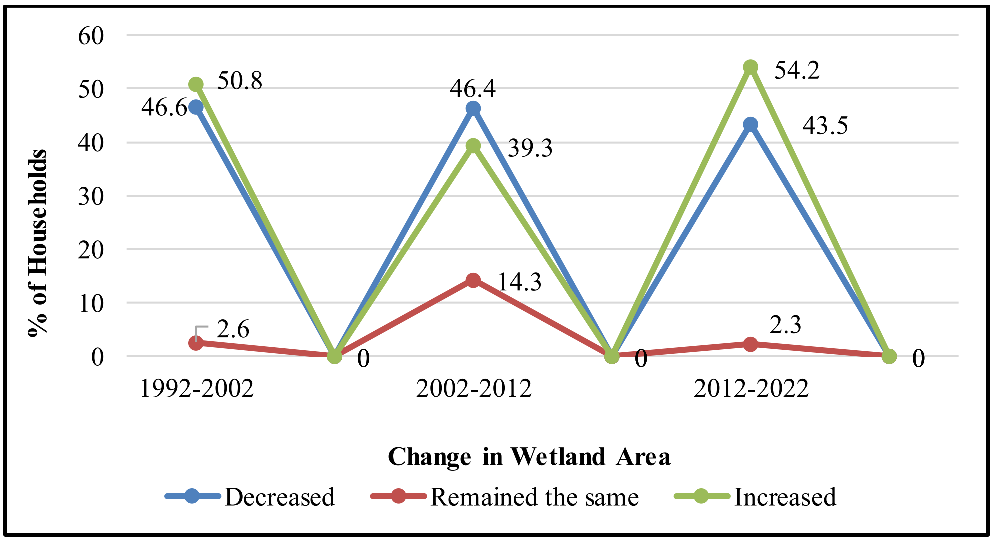

Figure 8: Household Heads' Views on Change in Wetland Area Between 1992 and 2022
Source: Field Survey (2024)

Comparing the image analysis and survey results, there is a fluctuating trend of increase or decrease in wetland area between the years 1992 and 2022. Wetland area changes within a given period of time, at least five years. Change in wetland area depends on change in class type coverage, where, for instance, vegetation area is converted to farmland, grassland, bare area, or settlement. This reduces the wetland area. Wetland area can also increase, for instance, when grassland area changes to water body or vegetation area as a result of long-term flooding due to heavy rains. The area can also increase due to lake water recession. Anthropogenic activities and natural occurrences define wetland coverage. Prolonged heavy rainfall, sustainable utilization of wetland resources, and protection of the wetland increase the wetland area. On the other hand, prolonged drought, uncontrolled utilization of wetland resources, and poor management of the wetland resources decreased wetland area due to encroachment and depletion of the resources, for instance, plant biomass.

Stakeholders' Perceptions on Sustainable Management of Nyando Wetland

Sustainable management indicators (Social, economic, and environmental) were used to determine perceptions of households on sustainable management of Nyando wetland. The results in Figure 9 show high negative perceptions of 62%, 65.1%, and 51.8% on quality of life, income level, and waste management, respectively. High positive perceptions were registered by 64.1%, 65.9%, and 59.9% of the households on the availability of plant biomass, the availability of animals and birds, and soil and water conservation, respectively. The negative perceptions of quality of life and income level may be attributed to low returns from the wetland. This may be as a result of wetland degradation, flooding, land disputes, or destruction of crops by animals and birds, as was reiterated by FGD participants. Direct observation at Ahero and West Kano Irrigation Schemes, and private farms in Kano and Nyakach, shows that birds destroy crops in the field, especially rice. A land dispute was also observed at the Miruka area in Nyakach, where Nyakach and Kano residents disagreed over the land boundary.

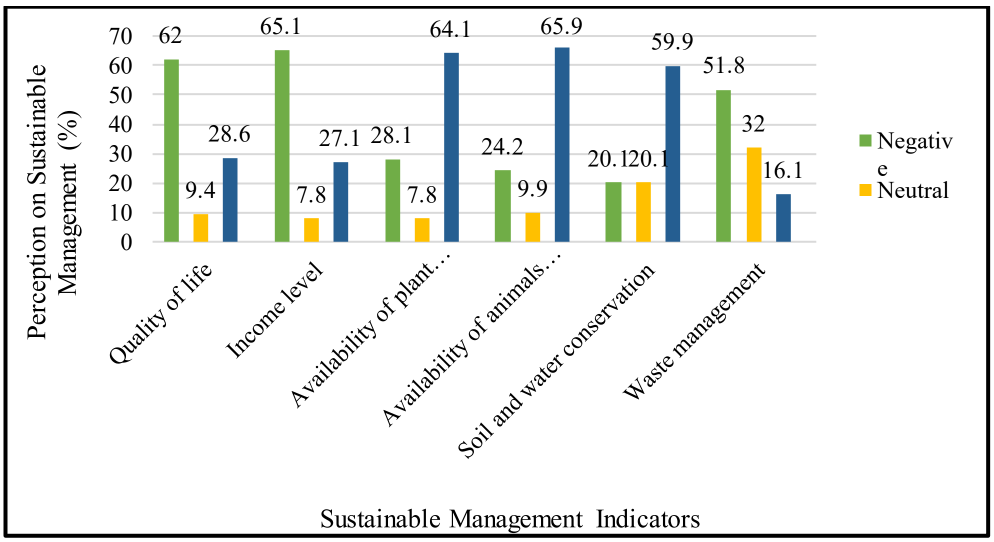

Figure 9: Perceptions on Sustainable Management of Nyando Wetland
Source: Field Survey (2024)

High negative perceptions of waste management may be a result of failure to understand why they must manage waste, yet they are practicing organic farming (98%) that minimizes waste disposal in the wetland. Focus Group Discussion (FGD) results also revealed that farmers practice organic farming because the wetland area is fertile. To this end, there is almost zero tolerance for the application of inorganic fertilizers, the use of pesticides, and other chemicals. Key Informants (KI's) have positive perceptions of waste management. As was observed, schools, health facilities, markets, companies and BMU's manage waste at the institutional level. Some schools are also involved in waste management at the wetland level through the Competency-Based Education (CBE) programmes. Even though households practice organic farming, KII, observation, and FGD results reveal that waste is deposited into the wetland as rivers empty into Lake Victoria. Observation, FGD, and KII results revealed a lack of seriousness in managing wastes because the wetland is a common-pool resource. The majority of the households are not ready to take responsibility. This means that few stakeholders are involved in managing the waste.

High positive perceptions registered on the availability of plant biomass, availability of animals and birds, and soil and water conservation may have resulted from households' view that plants, animals, birds, soil and water are natural resources that regenerate or recharge themselves. Focus Group Discussion (FGD) and KII results show that the resources are extracted with minimal concern for their availability in the future. The uprooting of papyrus roots was witnessed at Nduru beach for use as firewood. This interferes with papyrus regeneration. Conversely, it is at Nduru beach where protected fish breeding areas were mentioned as evidence of land use practice by the head of the resource user group. Therefore, uprooting of papyrus roots defies the sustainable practice because fish species require wetlands as spawning grounds and nursery areas for their young, especially parts dominated by papyrus and other plants. Key Informants (KI's) and FGD participants have positive perceptions of the sustainable management of Nyando wetland.

The Chi-Square test of independence revealed a significant association between change in wetland area 1992-2022 and perception on quality of life, income level, availability of plant biomass, availability of animals and birds; and soil and water conservation [χ^2 (4, N = 384) = 32.21, $p < .001$, χ^2 (4, N = 384) = 36.478, $p < .001$, χ^2 (4, N = 384) = 70.89, $p < .001$, χ^2 (4, N = 384) = 85.80, $p < .001$ and χ^2 (4, N = 384) = 14.02, $p = .007$ respectively]. Perception on waste management gave a result of $p > .05$ (χ^2 (4, N = 384) = 4.003, $p = .406$), meaning that it has no significant relationship with change in wetland area. This can be attributed to the fact that when the quality of life, income level, availability of plant biomass, availability of animals and birds, and soil and water conservation are influenced by a change in wetland area, waste management is not affected. Therefore, waste management does not worsen or improve with an increase or decrease in wetland area.

Discussion

From the findings of the study, it is evident that the Nyando Wetland area declined by 2269 ha (-27%) between the years 1992 and 2022. This is similar to the finding by Maithya (2021) that Nyando Wetland was reduced by -2,933.1 Ha (-24.4%) between 1985 and 2020. A decrease in the wetland area occurred due to both natural and human-induced factors. These include various human activities like agriculture and development; pollution, aquaculture, hydrological alterations, and climate change. Similarly, Maithya (2021) explains that the reduction in the Nyando Wetland area emanates from human disturbance from vegetation clearing and burning for agriculture and settlement, climate change and variability, and inefficient resource governance. Anthropogenic activities disrupt natural water flow, alter habitats and introduce harmful substances, impacting the health and extent of wetland ecosystems. In this state, the wetland is under pressure, and the end result is habitat loss and degradation

Nyando Wetland has been reclaimed for agriculture and development. This has taken the form of farming, tree planting, digging of canals, settlement, construction of water pumps, garbage disposal sites, and social amenities like schools and markets, among others. Drainage, grazing, mono-cropping, uncontrolled irrigation, and introduction of alien species like eucalyptus trees are the major causes of Nyando Wetland loss. This is caused by over-exploitation of the wetland resources through unsustainable practices like sand harvesting, overfishing, overgrazing, and overharvesting of plant biomass like papyrus. Papyrus has been depleted landward, making mat makers harvest papyrus lakeward using boats. Evidently, extractive practices are more intensified in Nyando Wetland than sustainable land use practices, resulting in an overall decrease in area. As explained by Abdullahi (2016), extractive land use practices result in interference with the normal hydrological cycle of the water through damming of rivers and construction of dykes, and reclamation of wetlands for large-scale agricultural developments.

The use of chemicals and inorganic fertilizers in fish ponds and rice plantations causes pollution in Nyando Wetland. This is aggravated by runoff from agriculture, industrial activities, and urban areas in the Nyando River Watershed, which introduces pollutants (sediments, nutrients, pesticides, heavy metals) into the Nyando Wetland. Pollutants degrade water quality and harm wetland organisms, resulting in wetland habitat loss. Therefore, farmers should be encouraged to use organic fertilizers. Similarly, Musasa & Marambanyika (2022) found that farmers should be discouraged from using inorganic fertilizers to enhance soil nutrients and resort to the use of organic fertilizers that are known to protect the environment. Apart from human activities, altered precipitation patterns and increased frequency of extreme events like drought and floods have damaged Nyando Wetland vegetation and altered water quality.

The effect of all these forces combined is a change in the Nyando Wetland cover type. Change in cover type culminates to change in wetland area because change in wetland area is either directly or indirectly proportional to change in cover types. When shrubland, reeds/papyrus, grassland, and waterbody areas are reduced, the wetland area is reduced. On the other hand, when farmland/bare areas increase, the wetland area decreases. This corroborates the finding by Assefa *et al*. (2021) that from 1992 to 2022, grassland, wetland, and vegetation land cover classes declined by 2,304.9 ha, 1410.2 ha, and 820.5 ha, respectively, whereas farmland, settlement, and bare land increased by 2,199 ha, 2,111 ha, and 225.4 ha, respectively, in Jimma City, Southwestern Ethiopia. This trend must be reversed through sustainable practices, for instance, controlled harvesting of papyrus, sustainable farming, controlled grazing, settling away from the wetland, controlled fishing, use of advanced irrigation like drip irrigation, and controlled pumping of water. Sustainable utilization of the Nyando Wetland resources will help the stakeholders to achieve maximum benefits and conserve the environment, hence social, economic, and environmental sustainability.

The findings show that households have high positive perceptions of the availability of natural resources in the wetland and their conservation (availability of plant biomass (64.1%), availability of animals and birds (65.9%), and soil and water conservation (59.9%)). The study also reveals that heads of institutions, county, NGO, and NEMA representatives, women groups, youth groups, fishermen, fish mongers, and the business community have positive perceptions of sustainable management of Nyando Wetland. Even though some households have negative and neutral perceptions on the availability of natural resources and their conservation, high positive perceptions show that stakeholders want to see Nyando Wetland in the future. Those who have negative and neutral perceptions take the wetland as a common property and do not prioritize conservation or preservation. Their participation in management activities is questionable because of the belief that natural resources regenerate. In addition, households have high negative perceptions of quality of life (62%) and income level (65.1%), showing that they are not satisfied with the wetland benefits. From the findings, therefore, stakeholders have divergent perceptions on the sustainable management of Nyando Wetland. Similarly, Kadoma *et al*. (2023) found that stakeholders hold divergent perceptions of wetland ecosystem services, perceiving them as a source of materials, fertile places for farming, cheap to buy and own, and "God-given". Nevertheless, Nyando Wetland remains an important resource base for livelihood and environmental sustenance.

Therefore, all stakeholders should come together and adopt a participatory approach to sustainably manage the wetland. This requires robust institutional arrangements at the national, regional, county, sub-county, and local levels. The arrangements should foster collaboration, integration and effective implementation of policies across sectors and scales. The key elements include strong national sustainable development strategies, participatory decision-making, and well-defined roles for different stakeholders. Besides, the sustainable wetland management strategies that should be implemented in Nyando Wetland to benefit both the environment and humans include managing water resources, restoring degraded habitats, controlling invasive species, and promoting community involvement. This will ensure the long-term health and functionality of Nyando Wetland. If Nyando Wetland is well managed, it will give stakeholders enough economic returns because well-managed wetlands are the most productive ecosystems in the world. Failure to conserve the wetland resources may result in food insecurity, low-income generation, and depletion of the available natural resources, hence failure to achieve the three pillars of sustainability.

Chi-square results show a significant association between change in wetland area 1992-2022 and perception of sustainable management indicators (Quality of life, income level, availability of plant biomass, availability of animals and birds, and soil and water conservation). Cramer's V values were significant (Cramer's V = .21, $p < .001$; .22, $p < .001$; .30, $p < .001$ .33, $p < .001$ and .14, $p = .007$ respectively) indicating a high strength of association. This implies that an increase or decrease in wetland area influences perceptions of sustainable management directly. An increase in area results in positive perceptions, while a reduction in area results in negative perceptions. This should guide the stakeholders to make informed decisions towards sustainable management of Nyando Wetland. The decisions require integration of ecological, social, and economic considerations. This involves understanding wetland functions, values, and the impacts of human activities. Therefore, stakeholder participation should be fostered in decision-making. In addition, accurate data, monitoring, and adaptive planning are essential for effective management.

Conclusions

This study assessed the influence of spatio–temporal changes on watershed stakeholders' perceptions of sustainable management of Nyando Wetland using a mixed research design. Change in wetland area influences perception of sustainable management. The analysis showed a statistically significant relationship ($p<0.05$), implying that an increase or decrease in wetland area influences stakeholders' perceptions directly. An increase in wetland area results in positive perceptions or a mindset that promotes social, economic, and environmental sustainability through involvement in wetland management. While a decrease in area results in negative perceptions of sustainable management.

Recommendations

Based on the findings of this study, the following recommendations are made to ensure that Nyando wetland is sustainably managed and well protected for ecological resilience;

- Restoration of the lost Nyando Wetland area through participatory wetland rehabilitation. This should be supported by the County Government of Kisumu, the National Government through NEMA, and the development partners. Continued utilization of Nyando Wetland should embrace wise use principles that integrate non-destructive uses of the wetland's resources to reduce livelihood pressures on the wetland. This will help enhance livelihoods for social and economic sustainability.

- Targeted communication, proactive engagement and educational initiatives to raise stakeholder awareness. Through this, all stakeholders will develop positive perceptions of the sustainable management of Nyando Wetland. Wetland management committee, local leaders, NEMA as a national government entity, and NGOs should promote such initiatives.
- Inclusion of a section that completely restricts settlement, construction of schools, development of industries and urban centers in wetland areas in the Draft EMCA (Conservation and Management of Wetlands) Regulations 2025. Seemingly, the Environmental Management and Co-ordination (Wetlands, River Banks, Lake Shores and Sea Shore Management) Regulations 2009 and the National Wetlands and Conservation Policy 2015 have not solved the problem of wetland encroachment. The extractive activities drain water from the wetland, resulting in wetland degradation and loss. In the end, the wetland area is reduced, leading stakeholders to have negative perceptions of the sustainable management of the wetland. Implementation of restrictions on activities like reclamation, water withdrawal, and construction by the government will help in the restoration of the lost wetland areas.
- Mandatory implementation of Kenya's National Wetland Conservation and Management Policy by both the county and national governments to achieve its set goal. The national government, in coordination with the county government, should ensure that wetland policies are implemented to conserve and protect its wetlands. Relevant laws such as the Fisheries Management and Development Act, the Water Act, and the Wildlife (Conservation and Management) Act should be adhered to. In addition, contradicting agricultural and land policies should also be harmonized. For example, land policies promote subdivision and formalization, yet agricultural sustainability requires consolidation and protection of large-scale farming. Unfortunately, policies and initiatives on community involvement and restrictions on activities like reclamation, water abstraction, and construction have not been implemented in Nyando Wetland.
- Creation of alternative livelihood options by the County Government of Kisumu, for example, development of Oseth, Nyamware, Ombaka, Kusa, Odega, and Ogenya beaches to attract tourists. This would ease pressure on Nyando Wetland and generate more income, hence improving the quality of life. In addition, the local community should promote ecotourism and introduce fruit trees to replace eucalyptus in Nyando Wetland for conservation and income generation.
- Further research on the application of Artificial Intelligence (AI) in Nyando Wetland monitoring and evaluation, and the influence of community participation in the design and implementation of Nyando Wetland management programs on acceptance and success.

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