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Spatial-Temporal Changes of Limoto Wetland Land Use/Cover Before, During and After Restoration Activities in Eastern Uganda

John Kameri Ochoko[1*], Bernad Barasa[2], Suzan Luyiga[1] & John Paul Magaya[3]
[1]Department of Biological and Environmental Sciences, School of Natural and Applied Sciences, Kampala International University, P.O.Box 20000, Kampala Uganda.
[2]Department of Geography and Social Studies, Kyambogo University, P.O. Box 1, Kyambogo, Kampala, Uganda.
[3]Department of Geomatics and Land Management, College of Engineering Design Art and Technology, Makerere University, Kampala-Uganda P.O. Box 7062, Uganda
*Corresponding Author's Email: johnkamerisnr@gmail.com

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Abstract

Purpose: Limoto Wetland is an arm of the Mpologoma wetland system in the Kyoga basin and is a vital ecosystem that supports rural livelihoods through the provision of various ecological goods and services. However, this ecosystem has been undergoing rapid degradation arising from competing land uses particularly paddy rice growing. In turn, this led to reduced capacity of the wetland to provide ecosystem services, thereby reducing the resilience of both the ecosystem and the livelihoods of adjacent communities. Interventions through a restoration program that introduced alternative livelihood options were instituted. It's important to document these changes to obtain insights that can aid decision-making for effective restoration and conservation. This study, therefore, sought to examine the spatial-temporal changes in Limoto wetland land use/cover transitions for the years 2015, 2020, and 2022.

Methodology: To quantify the wetland changes, remotely sensed imageries for 2015, 2020, and 2022 were utilized in classifying land use and land cover dynamics on Limoto Wetland through the Maximum Likelihood algorithm. A total of 500 points were collected from different land use/cover types and used as reference points to develop the image error matrices. Overall accuracy, producer's and user's accuracies as well as Kappa statistics were generated from the error matrices. A Kappa test was carried out to measure the extent of classification accuracy; the Kappa coefficient, K, being a coefficient of agreement. It reflects the difference between the actual agreement of classification with reference data and the agreement expected by chance.

Findings: Results generally showed that five years after the restoration program (2020), Limoto wetlands regained over 50% of previously converted wetlands to farming. Papyrus coverage also more than doubled from 3.4% to 11.35% of the total wetland coverage. Farms degraded over the past years (1986-2019). However, in 2022, wetland coverage declined drastically as farming took up more than half of the coverage (55%) land, and built-up areas also increased. These changes between 2015-2020 were majorly driven by the introduction of alternative livelihood options which vacated communities from the wetland.

Recommendation: The changes after 2020 were due to the unsustainability of the livelihood options and the effects of the Covid-19 lockdown which rendered only farming as the socio-economic activity, coupled with movement restrictions that curtailed monitoring and control of activities in wetlands by enforcers. The study recommends community-tailored, tenable, and sustainable alternative livelihood options to influence community-led wetland restoration and conservation to curb the continuous loss of this wetland.

Keywords: *Landuse Change, Livelihood, Spatial-Temporal, Wetland Restoration*

1.0 INTRODUCTION

Land use/cover spatial patterns of wetlands are often dynamic due to the intra-annual variations in ecosystem variables, whether driven by natural or anthropogenic influences (Rwanga & Ndambuki, 2017). Change detection of land use/cover changes presents a suitable platform to study about fragile and dynamic ecosystems such as wetlands (Kibet *et al.*, 2021). Several studies have revealed that the availability of precise and reliable land use/cover change information is not only beneficial but very critical for environmental planning for sustainable development as it enhances understanding of the anthropogenic influence on the terrestrial ecosystem (Nhamo *et al.,* 2017; Orimoloye et al., 2019; Papastergiadou et al., 2008; Rebelo *et al.*, 2009). Remote sensing technology has over time been adopted as a tool to detect, identify, measure, assess, and generate information on patterns of land use changes over wetlands in various parts of the world (Orimoloye *et al.*, 2019). Kaplan and Avdan, (2017) affirmed that remote sensing approaches can be used to monitor, classify, or manage wetlands. Remote sensing techniques used to classify wetlands include visual inspection and analysis, supervised classification, unsupervised classification, hybrid classification, and principal component analysis (Kaplan & Avdan, 2017). Haque and Basak, (2017) concluded that remote sensing was effective in providing a precise characterization of areas with a lot of fluctuation as well as those with slow and steady changes.

Using Landsat imageries, a combination of NDVI and NDWI indices were applied in land cover change detection of Tanguar Haor wetland, a Ramsar site in Bangladesh, in which it was established that about 40% of wetland cover had been converted to residential and agricultural land over 30 years period (Haque & Basak, 2017). In Kenya, remote sensing techniques have been used to assess land use/cover change detection in Rumuruti (Mwita, 2016), Nyando Wetland (Okotto-Okotto *et al.*, 2018), and Ombeyi Wetland *(*Nicodemus *et al.*, 2019) among other large wetlands. These studies cumulatively indicated that the landscape of Kenya's wetlands is actively transforming due to human-induced factors. The overall analysis found that mainly anthropogenic influence was behind the change. A recent study by Kibet *et al.*, (2021) on the land-use/cover changes and encroachment issues in Kapkatet wetland in Kenya showed a dwindling trend of wetland cover over the past thirty-three years (1986-2019). Arrays of anthropogenic activities were found to have contributed to the wetland loss with the land conversion for agricultural purposes being the most dominant economic driver of encroachment. Different classes used to deduce the changing pattern indicated variations with open grounds depicting an increasing trend within the selected periods.

Likewise, comprehension of the complex interdependence between LULC transitions and riparian rural livelihood can inform critical decision-making by policymakers, planners, and other stakeholders (Bunyangha *et al.,* 2022). Besides, the use of remote sensing and GIS in research showing causes of LULC dynamics on the landscape of small wetlands are very few while the spectral signatures acquired from satellite imagery for regions within the tropics exhibit minimal band dissociation capabilities amongst the various vegetation types (Hayri Kesikoglu *et al.,* 2019; Kaplan & Avdan, 2017; Kibet *et al.*, 2021; Orimoloye *et al.*, 2019). Moreover, past studies in the Lake Kyoga basin have focused in detail on the ecological, biological, and hydrological components (Gabiri *et al.*, 2018; Jones *et al*., 2013; Kansiime *et al.*, 2007; Namaalwa *et al.*, 2013; Orimoloye *et al.*, 2019).

Problem Statement/Gap

In the plight of increased human population pressure on Limoto wetland and its catchment zones, the study was critical and timely in understanding the inter-relationships that exist between the riparian rural population and natural resources use. Anthropogenic-induced changes and their impacts on LULC dynamics in Lomoto wetland are imperative and the use of local empirical evidence on the same, relevant stakeholders can use the information in formulating intervention strategies and sustainable land use systems in Limoto wetland. The study aimed at generating a characterized area estimate of Limoto wetlands’ land use and land cover change schema before, during and after restoration activities on Limoto Wetland for the period of 2015, 2020 and 2022 respectively. The study was timely in examining the spatial and temporal characteristic of anthropogenic impacts and their relationship with land use and land cover changes in Limoto wetland. The researcher has attributed the observed land use and land cover dynamics to aggregated decisions at the household level in response to policy interventions and Institutional Environmental Restoration programs.

Validation of the Model

Validation was done for both the delineated wetland boundaries and the classified wetland landuse/cover types. A total of 500 training sites were randomly created and visited for validation purposes after the classification. The points were visited to confirm if the classified classes correlated with ground information. The sampled points were reached with the help of using eTrex Garmin hand-held global positioning systems**.** *Accuracy assessment:* Accuracy assessment is important for verifying the quality of image output (Butt *et al.*, 2015). Kappa statistics incorporate classification errors. (van Vliet *et al.*, 2011; Rosenfield and Fitzpatrick-Lins1986). A Kappa test was carried out to measure the extent of classification accuracy; the Kappa coefficient, K, being a coefficient of agreement. It reflects the difference between the actual agreement of classification with reference data and the agreement expected by chance. In this study, the Kappa coefficient was calculated using equation (Congalton, 1991).

$$K = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_{i+} * x_{+i})}{N^2 - \sum_{i=1}^{r}(x_{i+} * x_{+i})}$$

where,

K = Kappa Coefficient, r = number of rows/columns in the error matrix, N = the total number of samples, xii = sum of correctly classified samples, $xi+$ =row I total, while $x+i$ = column I total.

2.0 METHODOLOGY

Location of the Study Area

This study was conducted in the Limoto wetland located within the Kyoga plains, Eastern Uganda *(Figure 1).* It lies between latitudes1010’0N’’ and longitudes 33057’0” E with an average elevation of between 1040m above sea level around Lake Lemwa and to1060 m above sea level within the floodplains. It is an arm of the bigger Mpologoma wetland system which is dominant within these plains. The wetland covers a total area of 136sq.km, of which 70% is in the Pallisa district and 30% is in the Kibuku district. Limoto wetland is characterized by small-scale subsistence agriculture, mainly of annual crops, limited pastoralism, and a high level of food insecurity (UNDP, 2016). The human population density is moderate by national standards at 260 persons per km^2. The annual rainfall range is 900-1500 mm, and the vegetation is mainly composed of savanna species namely (Bunyangha *et al.*, 2022).

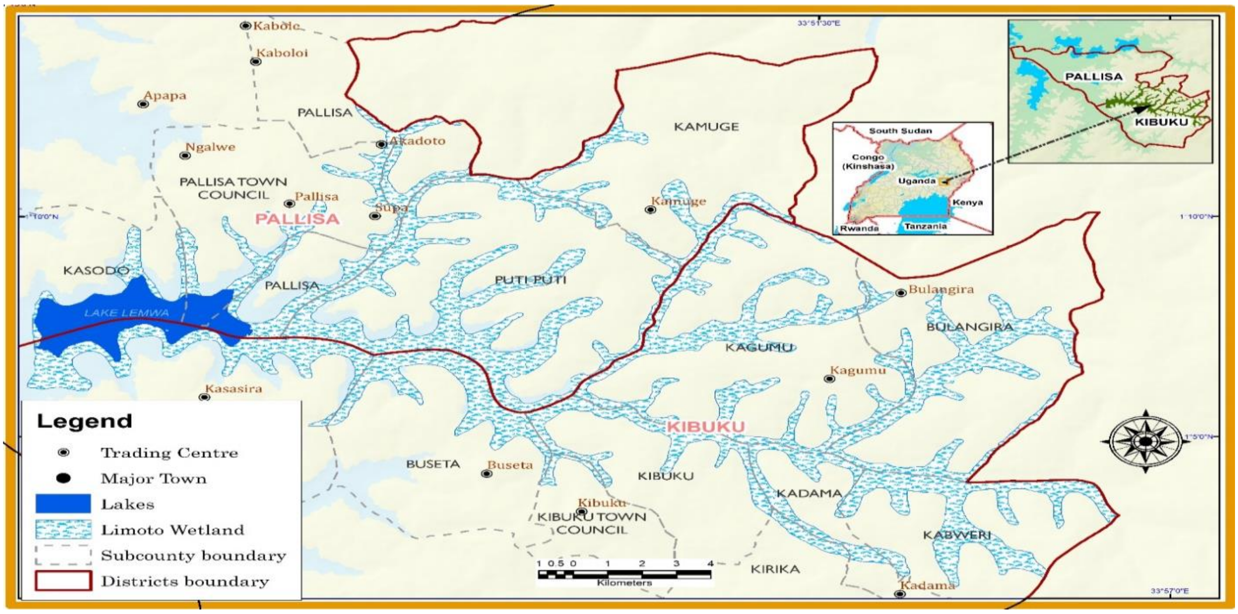

Figure 1: Location and Map of Limoto Wetland

Source: Author, 2022

Data Collection Methods

Satellite Images Acquisition

A user pre-processed and analyzed a set of sentinel photos obtained for free from the Sentinels Scientific Data Hub [https://scihub.esa cloud-free. int] to assess changes in land use and cover. The study's photos were taken during the same dry season months of January through February, when the spectral reflectance was relatively similar. However, the photos had to have a minimum of 20% cloud cover to meet the selection requirements. The excellent quality, frequent 5-day repeat cycle, and ease of downloading made the Sentinel photos the favored choice (Grivei et al., 2020). The Sentinel satellite has an optoelectronic multispectral sensor for surveying with a sentinel-2 resolution of 10 to 60 m in the visible, near-infrared (VNIR), and short-wave infrared (SWIR) spectral zones, including 13 spectral channels. This sensor ensures the capture of differences in vegetation state, including temporal changes, as well as minimizing impact on the quality of atmospheric photography (Fernandez et al. To assess land use/cover changes in and around the papaya wetland, the sentinel scene requirements for the years 2015, 2020, and 2022 were obtained, processed, and evaluated.

Table 1: The Image Acquisition and Specifications

Satellite/ Sensor	Date	Tile No.	Band No.	Resolution
Sentinel 2A	2022/01/29	T36NWG	4,3,2	20m
Sentinel 2B	2020/01/30	T36NWG	4,3,2	10m
Sentinel 2A	2015/02/22	T36NWG	4,3,2	20m

To further understand the factors that have caused wetland use/cover change and are facilitating the re-encroachment of Limoto Wetland, a literature review was done to identify policies that were implemented and institutional arrangements during the period of analysis. In addition, a comparison between population densities and wetland use/cover changes was done.

Descriptive Survey

Household Survey

The researcher developed a self-administered survey questionnaire to collect quantitative information from wetland users using a Kobotool box uploaded to tablets. Using research assistants who administered the questionnaires targeting the randomly selected respondents consisting of both males and females. The research assistants translated the survey questionnaire into the local Ateso and Lugwere languages, the dominant languages used in the study area for the respondents who did not understand English. The questionnaire covered the demographic characteristics of the respondent (e.g., age, gender, household size, age segregation by sex, religion, and occupation), and land characteristics (e.g., land size, land uses, land tenure, etc., decision-making on land). The purposive sampling technique was adopted to identify households located within a radius of ≤1 km from the wetland and those whose parcels of land extend to this wetland. The number of 273 respondents was targeted by the research proposal, however, a total of 405 respondents from Pallisa (249) and Kibuku (156) districts were interviewed due to the efficacy of the data collection using the Kobotool box software uploaded on tablets, and well-trained research assistants. The respondents were males (58.3%) aged 41.9 years and with farming (94.1%) on their land (82.5) as the main occupation. In cases where an adult was not available or not willing to be interviewed, the next household was chosen. The purpose of the study was explained to the respondents, and anonymity of response confidentiality, and data protection were emphasized. The data from the household survey were entered and coded using SPSS software and thereafter, quantitative data was subjected to descriptive statistics to obtain frequencies and percentages.

Key Informant Interviews

An interview guide was designed with appropriate questions for respondents in the policy, regulatory and political leaders, mainly targeting wetland managers, local council politicians, and law enforcement. The questions followed a flexible format beginning with general themes and then moving to specifics and probes. The interview exercise was only carried out after having explained the purpose of the interview, assuring the interviewee of the confidentiality of the information, and obtaining their explicit consent. Five key informants were identified and interviewed. The wetlands management department under the Ministry of Water and Environment who are the restoration implementing institution, the Eastern Regional wetlands officer and communication specialist, the project coordinator at IUCN for the Limoto restoration project, the District Natural Resources officers for both Pallisa and Kibuku, Senior environment officer of Pallisa district and 4 Opinion leaders each from Limoto, Bungole, Natooto, and Katome parishes.

Focused Group Discussions (FGDs)

One FGD was arranged for local council chairpersons (LC 1) purposively selected from eight villages where the 4 opinion leaders did not come from to avoid duplication. These were Kadwaraka, Akisim, Kaitambiri, Kakoro, Petete, Katome Central, Limoto B and Buseta. Eleven participants other than the facilitators, attended the FGD.

Data Analysis and Processing

Image Processing and Classification

Sentinel images were resampled from 20m spatial resolution before image analysis. The resampled images (20m) were later atmospherically corrected using the Dark Object Subtraction procedure to minimize the impact of the atmosphere on the sensor. The method searches and removes dark pixel values. For the pre-processed images, the areas of interest were masked out for faster rendering. The masked images were classified using a hybrid of supervised and unsupervised classification algorithms in ArcMap software version 10.8 for spectral reflectance clustering because of the heterogeneity of land use/cover types in the case study area. This algorithm provided land use/cover spectral classes in and around Limoto wetland system. The definition and description of land use/cover classes were based on field knowledge and observations. However, this study was limited to seven land cover types; the classes included the built-up area, Bushland, Farming, Grassland, Open water, Papyrus, and Woodland as described below (Table 2).

Table 2: Description of the Major Land Use/Cover Types

Land use/cover classes	Description
Built-up area	Scattered rural settlements closely associated with cultivated land and urban settlement
Bushland	Remnants of distributed vegetation that is not cultivated but with trees, shrubs, and other vegetation
Farming	Land allotted for crop cultivation both annual and perennial crops.
Grassland	An open area of land covered with grass especially one used for grazing
Open water	An area having surface water. It includes pond water, streams, rivers, lakes, marshland, and riverine trees found along riverbanks and streams.
Papyrus	Is a sedge that naturally grows up to 16 feet tall in swamps, shallow lakes, and along stream banks
Woodland	Land covered with densely scattered trees with grassland underneath

Remote Sensing Analysis

To analyze the change patterns of Limoto wetlands before and after restoration interventions, a post-classification detection method was employed to perform wetland use/cover change detection. Three important aspects of change detection were considered; (1) detecting the changes that have occurred, (2) identifying the nature of the change and, (3) measuring the area extent of the change. This analysis produced change maps showing a complete matrix of changes for example from vegetation to bare ground. Quantitative area data in hectares and their percentages, as well as gains and losses in each wetland use/cover class, was then compiled.

3.0 FINDINGS

Wetland Use Changes

The land use changes of the Limoto wetland system over the three years are shown in Figure 1. Initially, in 2015 the Limoto wetland predominantly comprised the Built-up area, Bushland, Farming, Grassland, Open water, Papyrus, and Woodland *(Table 3, Figure 2).* Table 3 and Figure 3 show the land-use classes in their respective area and percentage coverage over the 7 years disaggregated by the 5 years and 2 years intervals inclusive of the marginal total areas of the study area.

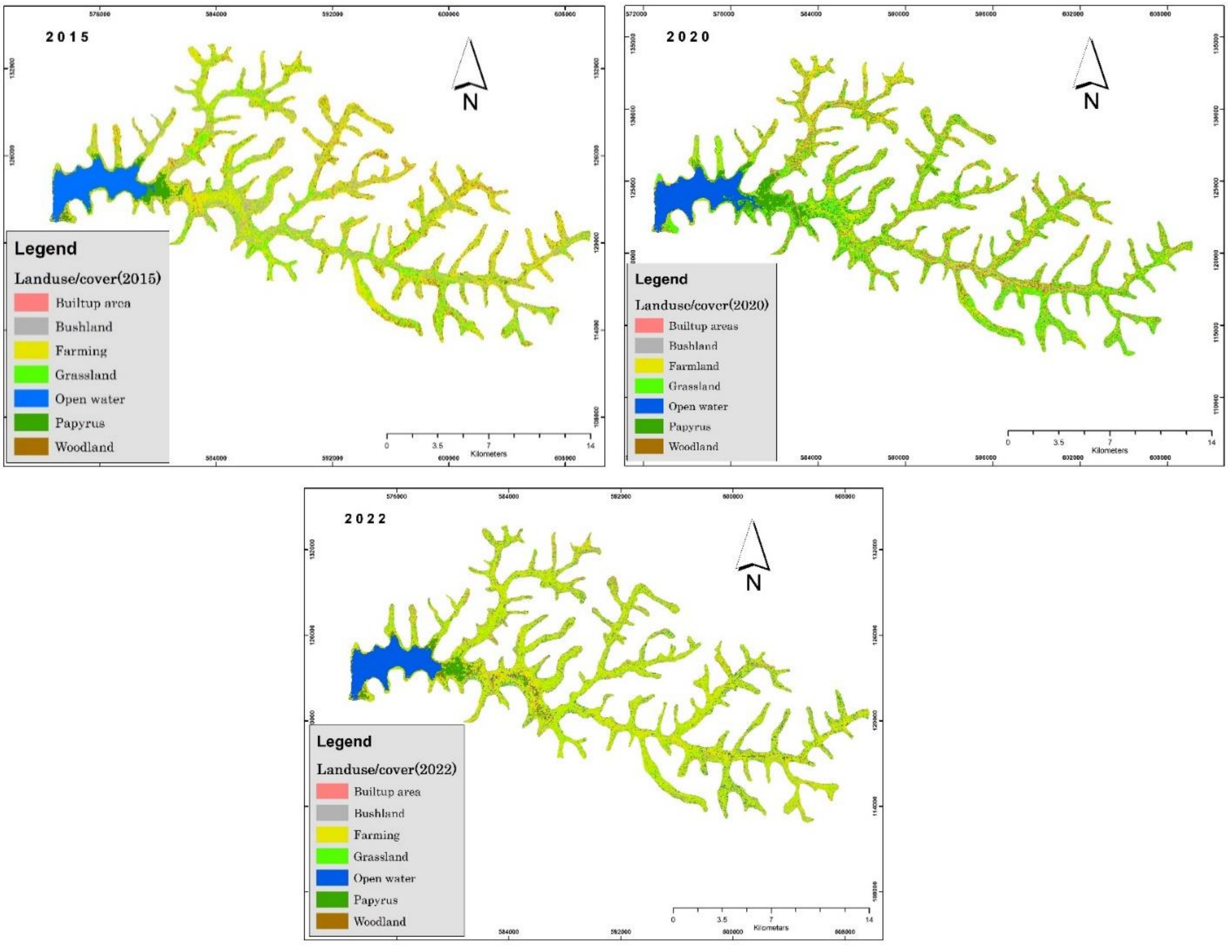

Figure 2: Classified Land Use and Land Cover Maps for Limoto Wetland (2015, 2020 and 2023)

The results indicate that the extent of land uses and land cover change varied drastically throughout the study. Built-up area, Bushland, Farming, Grassland, Open water, Papyrus, and Woodland all shows tremendous transition during the 7 years study period. Farming dynamics (2015-2020) experienced a huge transition from a total of 52.2% of cover to a 26.7% decline in 2020 and later increased to 55% in 2022 *(Table 3).* The same pattern of transition was observed in bushland experiencing a slight change from 12.9% and declining to 11.8% between 2015 and 20220 respectively. Bushland continued declining in 2022.

Table 3: Area in Sq.Km and Percentage Share of Land Use and Land Cover of Limoto Wetland from 2015 to 2022

	2015		**2020**		**2022**	
Landuse/cover	**Area(sqkm)**	**%**	**Area(sqkm)**	**%**	**Area(sqkm)**	**%**
Built-up area	0.92	0.7	1.4	1.0	6.2	4.5
Bushland	17.58	12.9	16.1	11.8	4.8	3.5
Farming	70.88	52.2	36.4	26.7	74.7	55.0
Grassland	19.24	14.2	39.9	29.2	23.4	17.2
Open water	12.73	9.4	13.2	9.7	20.8	15.3
Papyrus	4.61	3.4	11.3	8.3	3.4	2.5
Woodland	9.94	7.3	18.1	13.3	2.6	1.9
Total	**136**		**136**		**136**	

Unlike farming and bushland, all land covers drastically increased between 2015- 2020 and fluctuated in 2022. Grasslands showed the highest restoration (29.2%) followed by woodland (13.3%), open water (9.7%), and papyrus (8.3%) in 2020. In 2022, all land covers were observed to decline in the interest of increasing land uses. Therefore, Woodlands (1.9%), Papyrus (2.5%), and bushland (3.5%) were highly degraded in the Limoto wetland system by 2022 *(Table 3).*

Wetland Cover Changes

The inconsistent changes in land cover trends in the Limoto wetland system between 2015 - 2022 are a key indicator of wetland degradation as illustrated in Figure 2 and Table 4. In 2022,

Table 4: Limoto Wetland Degradation Statistics between 2015 -2022

	2015		**2020**		**2022**	
Degradation status	**Area(sqkm)**	**%**	**Area(sqkm)**	**%**	**Area(sqkm)**	**%**
High	71.8	52.8	37.8	27.7	80.9	59.6
Low	64.1	47.2	98.5	72.3	54.9	40.4
Total	**136**		**136**		**136**	

Results show that, within a trend of 2015, 2020, and 2022, the highest degradation levels were observed in 2022 (59.6%) and the period before 2015 (52.8%). The most Intact wetland was observed in 2020 (27.7%)-Table 4. Farming is observed to be at 55% covering more than half of the wetland. This is a drastic change from 26.7% in 2020. The built-up area also gained to 4.5% from 1% in 2020.

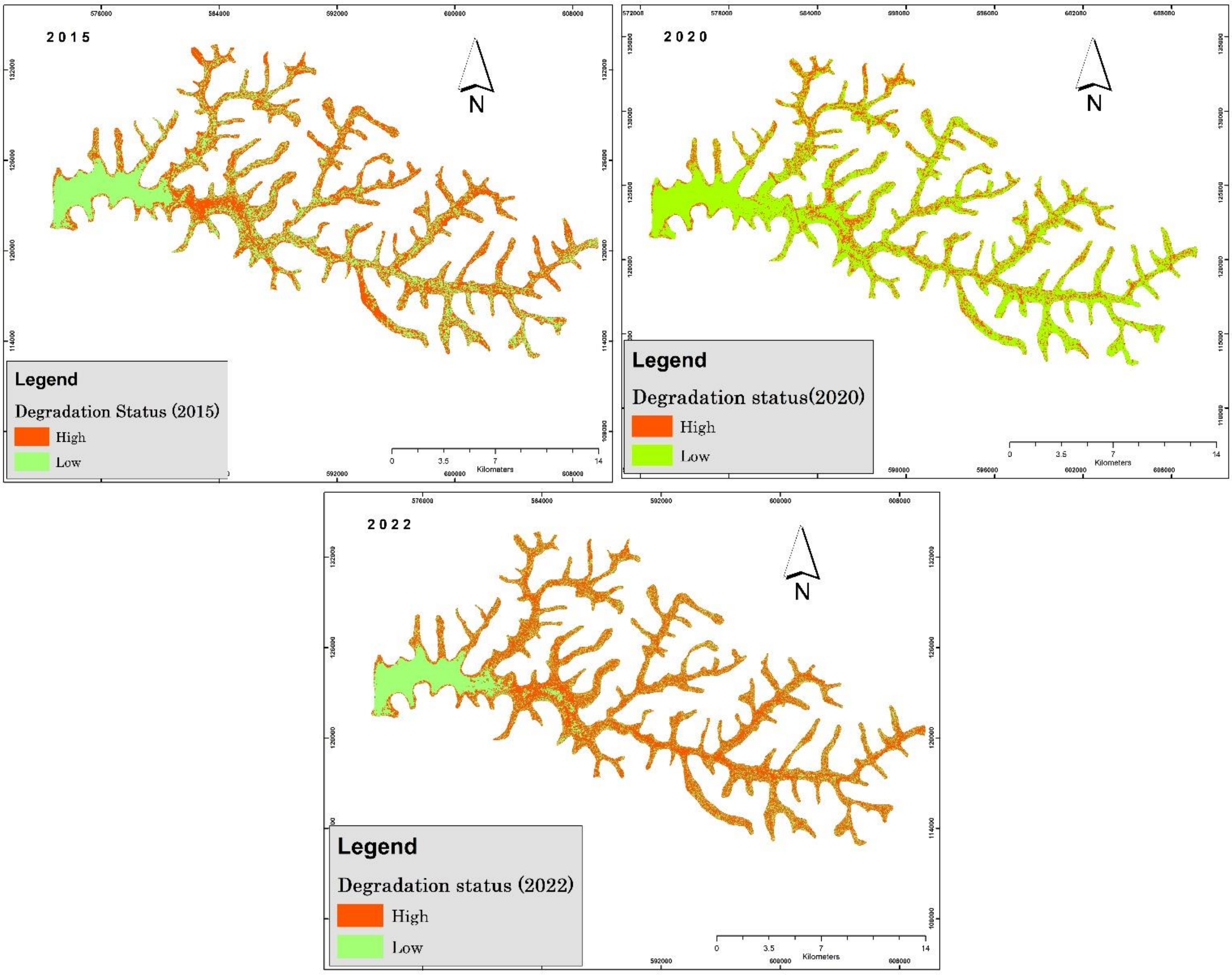

Figure 3: Spatial Distribution of Wetland Degradation between 2015-2022

Discussion

In the period between the year 2015 and the year 2020, the Farming land area experienced a huge transition from a total of 52.2% of cover to a 26.7% decline in 2020. This is the period when the restoration activities were implemented by forceful eviction followed by the use of alternative livelihood options. The FGD key informant interview confirmed that the alternative livelihood options had a positive impact on LULCC in Limoto wetland. Key informants linked land use and land cover changes in the study area after 2015 to forceful eviction and the introduction of alternative livelihoods which started registering an increase in household income from the sale of yields from the crops grown using the established mini irrigation system, milk from heifers, eggs from Turkeys, products from beekeeping, fish from the fishponds and piglets from the guilts that were distributed. 87% of the respondents agreed that the initiatives increased interest, awareness, and eventual comprehension of the value of wetlands and their importance for local communities and policymakers. One key informant linked the regaining and revegetation of the once degraded Limoto wetland by 2020 to the interventions through alternative likelihood options which had vacated the encroachers from depending on it. In 2022, a big transition is observed with farming (55%) and built-up area (4.5%) gaining big coverage in the wetland as compared to 26.7% and 1% in 2020 respectively. This might be attributed to the continued relaxation in monitory activities caused by insufficient funds following the departure of the founders of the restoration activities. More than half (51.8%) of the respondents claimed that alternative livelihoods promoted the loss of farmland and caused food shortages. This was affirmed by the key informants who that the Turkeys and fingerings brought were of poor quality and failure by the flagship livelihood option of the fish ponds. Key informants also faltered politicians who in looking for political mileage in the wake of the 2021 elections, advised communities to return to the wetland to meet their rising cost of living. Key informants also noted the Covid-19 lockdown which only left agriculture as the only economic activity encouraged by the government, introduced new encroachers in addition to the previous ones who had vacated the wetland. This was compounded by limited monitoring and control by enforcers due to movement restrictions during lockdown leaving encroachment to flourish. Focus group discussion linked land use and land cover changes in the study area to population growth in the area. As the population increased, the need for more settlements (built-up 4.5%) and the demand for food (farming 55%) increased correspondingly. Also, the continued belief that the wetland where encroachers were vacated is family land could have accelerated the re-encroachment. Similarly, several researchers have attributed agricultural expansions in various parts of the world to be at the expense of land covered with natural vegetation (An & Verhoeven, 2019; Barakagira & de Wit, 2017; Bunyangha *et al*., 2022; Mombo, 2017; Sakataka & Namisiko, 2014).

4.0 CONCLUSION AND RECOMMENDATIONS

This study has provided data to show that there have been significant changes in wetland cover in Limoto wetland between 2015 and 2022. The study set out to examine the trend of spatial-temporal changes in Limoto wetland use/cover transitioning for the years 2015, 2020, and 2022. The focus is the 7 years disaggregated by the 5 years and 2 years intervals under which restoration activities were supported by alternative livelihoods were implemented. The alternative livelihood options between 2015-2020 were able to vacate encroachers from Limoto wetland thus restoring the ecological functions of the wetland. However, after then, the alternative livelihood options were no longer sustainable and failed to be effective in economically meeting the expectations as predicted compared to the initial paddy rice growing. The effect of Covid-19 cannot be underestimated as the lockdown only left agriculture as the economic activity to sustain livelihood within the study area. The Covid-19 lockdown also came with movement restrictions which curtailed monitoring and control of restoration activities hence leaving encroachment to flourish.

In this study, the magnitude of land use/cover changes in the Limoto wetland from 2015 to 2022 were quantified. Land cover changes have occurred over the study period. However, farming is again the main type of land use. The findings also depict that poverty levels coupled with the low level of education significantly affected the land use/cover dynamics in the study area. Similarly, the status of land cover and its dynamics have serious environmental and socio-economic implications at the local level and beyond. The alternative livelihood options need to be revised in consultation with the community to be appropriate tenable and sustainable. Based on these results, the study recommends further studies to investigate the appropriate, tenable, and sustainable livelihood options based on the scientific finding.

Conflict of Interest

The Author declares no conflict of interest from any sources.

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