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Assessing the Impact of Land Use Change on Hydrology and Vegetation Health in Okole Wetland, Lira City Using NDWI and NDVI

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ABSTRACT

The study examines the land use changes in the Okole wetland between 2010 and 2020, assessing their impact on flora, productivity, and vegetation health. Three satellite photos were used to calculate NDVI and NDWI, with kappa coefficients of 88.4%, 85.96%, and 86% respectively. The primary land use and land cover categories were built-up areas, sparse forest, open water, thick forest, permanent swamp, and seasonal swamp. Grasslands and agricultural landscapes were also present. The study found a decline in woods (6.7%), grasslands (9.5%), open water (1.3%), and permanent swamps (6.7%), while a rise in seasonal swamps (13.2%), agricultural land (5.5%), and built-up areas (5.5%). The study concludes that improving knowledge and compliance with land use changes in wetlands is crucial to prevent ecosystem degradation and maintain natural water supply equilibrium.

Keywords: Land use change; Wetland hydrology; Vegetation health; NDWI; NDVI

INTRODUCTION

A wetland is a geographical location that combines the qualities of both water and dry ground. Generally, wetlands are found in low-lying places that get freshwater from lakes, streams, and rivers at their termini, or saltwater from tides in coastal regions shielded from waves. Thus, a wetland is defined as an area that is continually or sporadically submerged in freshwater or saltwater up to a depth of six metres. A wetland may also be thought of as an ecosystem that forms when water builds up and creates soils that are dominated by anaerobic processes. This drives the biota, especially rooted plants, to adapt in order to withstand floods. [1, 2]. Wetlands are regions that are periodically or continuously inundated by water, to which the plants and animals there have adapted, according to Uganda's National Environment Act [3]. Wetlands have characteristics that makes them fall between true aquatic systems and terrestrial systems. When a wetland is found, the water table is typically at or close to the surface, or there is shallow water covering the ground. [4]. Wetlands make up around 6% of the earth's surface area. The distribution of the 2303 Ramras Sites across continents is not uniform. Africa has more sites than Europe, although Europe has more sites overall. Three or four impact variables touch more than half of the sites. The use of biological resources (53%), pollution (54%), natural system change (53%), and agriculture and aquaculture (42%), are the most major effect causes. Since the wetlands' land area and environment are the primary things affected, this happened in 75% and 69% of the locations, respectively [5, 6]. The sector performance report of the Ministry of Water and Environment states that the percentage of wetlands in Uganda is 8.9% intact, 4.1% degraded, and 2.6% entirely gone. There are two main types of wetlands in Uganda: wetlands connected to lakes, or lacustrine wetlands, and wetlands connected to rivers, or riverine wetlands. Among the lacustrine kinds are the Bunyonyi lake/swamp complex, Bisina and Opeta, Wamala, and numerous smaller lakes. The Kyoga/Kwania complex consists of Lake George, Lake Edward, and Lake Albert. The Okole and Kafu systems are two examples of riverine wetlands. People benefit from a wide range of ecological services that wetlands offer. Regulation, supply, support, and cultural ecosystem services are a few of them [4, 7].The biotic and non-biotic aspects of the soil, water, vegetation, and wildlife make up the two halves of the wetland system. The functions that result from the interactions between these constituents include the cycling of nutrients, raw materials, sedimentation, filtration, replenishment of groundwater, and atmospheric water vapour [8]. Even in controlled environments, there are reports that environmental exploitation alters how ecosystems naturally function. When the exploitation of delicate ecosystems, like wetlands, continues unchecked, the impacts became more severe. There is evidence from sources indicating that unchecked wetlands invasion has resulted in significant losses in biodiversity and degradation of wetland areas globally [9]. There are unmistakable signs of knowledge and technological gaps that prevent the implementation of techniques linked to sustainable land management (SLM) [5, 10, 11]. One of the obstacles is that land users are not aware of the land degradation that is currently occurring in the various wetlands and how it is connected to the wetlands' diminishing ecosystem services. The reason for this constraint is the lack of financial support and investment from both domestic and foreign sources for studies and research that are particular to a given area and can measure the extent of land degradation. Availability of information about the health status of wetlands could help to provide the pressure necessary for protection measures and allocation of resources to conserve those wetlands with high risks of being highly degraded. Okole wetland, located in Lira City has for so many years had uncontrolled activities such as animal grazing, build-up, bricks laying, charcoal burning, horticulture, craft works and currently Agro-base factories being established and commercial rice growing which could cause negative changes in the hydrology and degradation of vegetation in the wetland. There is need therefore to carry out studies that will potentially indicate the impacts of these activities on the hydrology and vegetation health of Okole wetland and this study will contribute to the body of scientific knowledge with regards to this problem by assessing hydrological changes that is to say changes in the extent of water and vegetation water stress in Okole wetland.

MATERIALS AND METHODS

Study Area

Northern Uganda is home to Lira City, which is situated between latitudes 2°14'6" N and longitudes 32°54'35" E. The district has a total area about 1,326 km^2, of which 3.1% is made up of forest and 1.9% is made up of open water and swampland. The East and West Divisions of the City consist of 236 cells/villages and 49 wards/parishes, which are the lower local governments; the parishes and villages are administrative units [9].

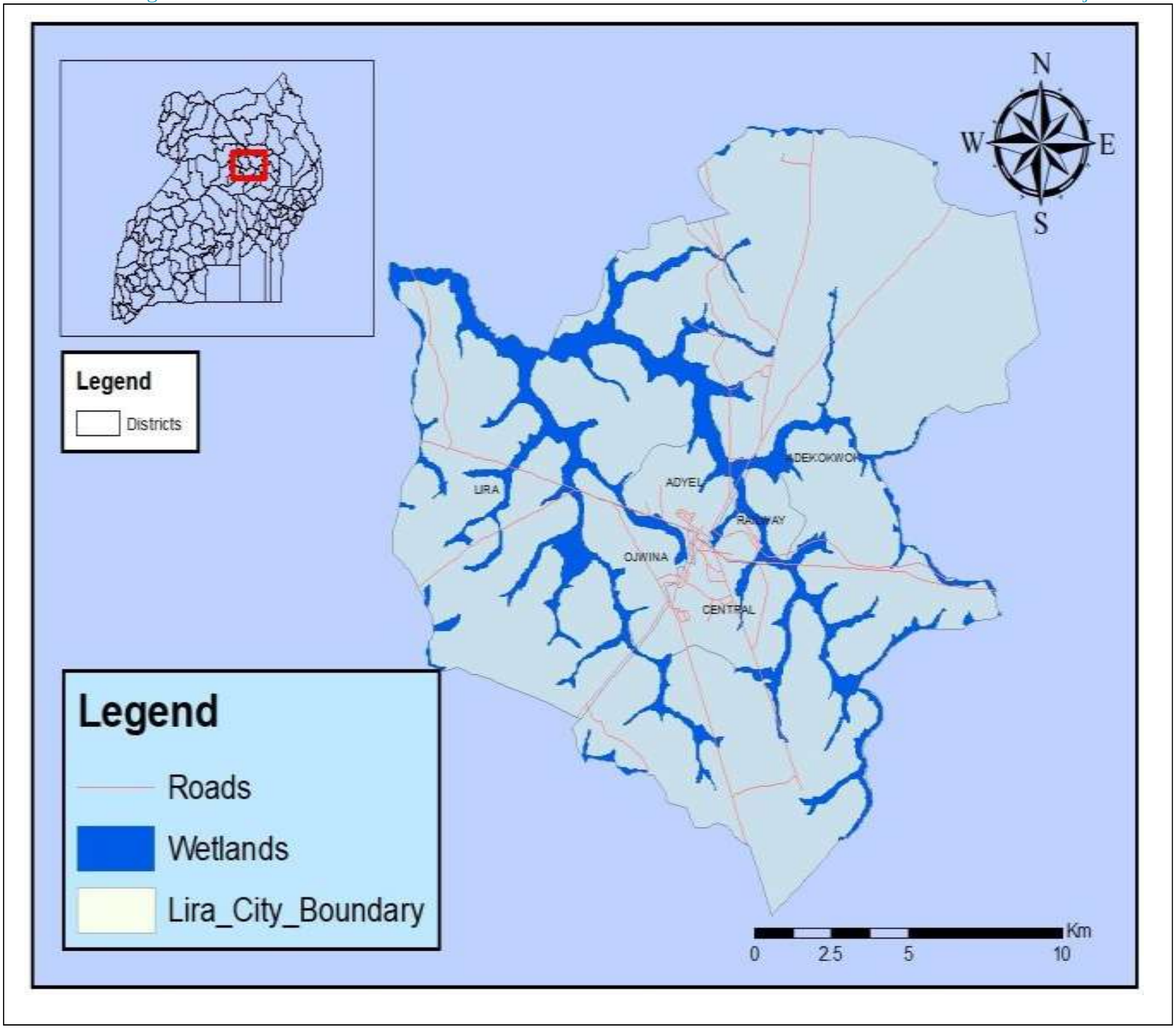

Figure 1: Study area map of Okole Catchment

Data Collection Method

Three satellite pictures were acquired from *https://earthexplorer.usgs.gov*. in order to evaluate the land use changes that have taken place in Okole during the last ten years. Specifically, the images were taken in the years 2010 and 2020, with 2010 serving as the base year. Table 1 shows the three satellite photos that were downloaded.

Table 1: Image data characteristics

Image Type	Date of capture	Processing level	Path number	Row number
Landsat8 OLI/TIRS combined	16th February, 2020	L1TP	172	058
Landsat5 Thematic Mapper	6th January, 2011	L1TP	172	058
Landsat7 Enhanced Thematic Mapper	2nd January, 2001	L1TP	172	058

All the three images were within the acceptable cloud cover limit of 10%. The images that were considered suitable for downloading had to have been acquired in the dry season that is either in December, January or February to avoid differences that could be brought about by season in the status of the study area. The extent of the study area was digitized and clipped from an online base map which was then used to extract the area of study from the RGB composites of the downloaded satellite images by masking. Supervised classification was done on the extracted RGB composite images to come up with Land Use Land Cover maps of the study area.

Change Detection in Land Use and Land Cover

In order to identify which land-use or land-cover class is moving to the other, this study conducted categorization comparisons of land cover statistics. From the attribute table of each identified image, the areas covered by each land cover category for the several research periods—2010, 2015, and 2020—were obtained and compared. In Microsoft Excel, the changes were calculated by deducting the area of each land-use orland-cover class from that of a prior year; that is, 2020 was subtracted from 2015, and 2015 was subtracted from 2010. This allowed for the determination of the positive or negative changes in each type of land cover. This study viewed a modification as beneficial. as a rise in the area covered by a certain land-use or land-cover class, whereas a fall in the area covered by a specific land-use or land-cover class was considered a negative change.

Evaluation of the Effects of the Land use Changes on the Water Content of Okolewetland

In order to evaluate the impact of land use changes on the water content of Okole wetland, the Normalised Difference Water Index was calculated using the matching bands of the downloaded satellite images using the raster calculator in the Arc GIS toolkit based on the following formula.

$$\mathbf{NDWI = (NIR\text{-}SWIR) / (NIR + SWIR)}$$

Evaluation of how changes in land use may affect the health of the vegetation This was accomplished by utilizing the raster calculator in the Arc GIS toolkit to calculate the Normalized Vegetation Index using the corresponding bands of the downloaded satellite pictures, using the following formula;

$$\mathbf{NDVI} = (\mathbf{NIR} - \mathbf{RED}) / (\mathbf{NIR} + \mathbf{RED})$$

Land Use Land Cover Types

Table 2: LULC types in and round Okole

Land Use/Cover Types	Description
Built-up	All of these structures are semi-permanent or permanent and house both people and other infrastructure like industries, roads, and buildings in towns or trading hubs.
Wetlands.	These are regions with both herbaceous and woody plants that are either constantly or sporadically wet.
Bush Areas	characterised by areas of tree cover within savannah grasslands.
Farmland.	This includes land that is farmed for both commercial and subsistence uses. It consists of newly planted crops as well as previously cleared ground that is ready to be planted.

Data Analysis

i) Supervised Image Classification

The RGB composite images, which were produced by combining the Red, Green, Blue, and Near-Infrared bands of the images using the composite band tool under data management tools in the Arc Toolbox, were subjected to supervised image classification in order to evaluate the changes in land use. Pixels that depict patterns that might be found using Google Earth were chosen for this procedure and used as training samples. The training sample drawing tools on the image classification toolbar were utilized to construct these training samples, which were then used to determine the classes and compute their signatures. A polygon was chosen as the training sample from the classification tool bar and drawn on the input picture layer in order to construct a training sample point. Classes that overlapped were combined into a single class using the merge tool in the training sample manager window after the training samples were created. The training sample points were then loaded and stored after each class's display colors was altered to make them stand out from one another. Next, a signature file was created using the create Signature File tool included in the training sample management window. The maximum Likelihood Classification tool in the image classification toolbar was used to categorise the picture using the signature file created especially for that input image. This tool assigns each pixel to one of the numerous classes based on the means and variances of the class signatures, which are kept in a signature file.

ii) Land Use Land Cover Change Detection

Change detection was used to determine if one class of land use or land cover is changing. To identify changes in land use and cover, this study used a classification comparison of land cover statistics. The areas covered by each kind of land cover over the several research periods were compared. The direction of change, whether positive or negative, for each category of land cover was then determined: The area covered by each class or land use land cover type in square kilometres was calculated using the formula Area = (count*30*30)/1000,000,000) and added to each classified image's attribute table. Changes in land cover and usage were calculated in Microsoft Excel using the land cover area data given in the attribute table of each recognised picture. Stated otherwise, the area of each class or land use land cover type of the current year was removed from the corresponding class or land use land cover type of the previous year, thus 2020 was subtracted from 2010 and 2010 from 2000. After then, these modifications were shown using a Microsoft Excel bar graph.

iii) Accuracy Assessment of the Classified Images

To measure the accuracy of the classification, this required comparing the categorized photos to reference data from Google Earth, which was taken to be accurate because of the high quality of the image. Reference information/ground truth data was gathered by analyzing high-resolution Google Earth Pro images captured during the same season and year as the study's chosen years, 2010, 2015, and 2020, using the historical imagery window. The images were taken in the same geographic location as the study area. Shape files in Arc Map were created using the class kinds or land use land cover types at particular locations on the categorized image, which were chosen at random. These points were loaded and superimposed over the Google high-resolution picture to determine and document whether the class type on the categorized map is the same as the class type established from reference data by comparing it to the real class type or land use land cover type that is on the high-resolution image (ground) of the study area on Google Earth. The responses were entered into a contingency table and utilized to create an error or confusion matrix. This matrix was then used to compute the kappa coefficient and total accuracy using the following formula:

$$\textit{Overall Accuracy} = \frac{\textit{Total Number of correctly classified pixels}}{\textit{Diagonal Total numbers of reference pixels/points}}$$

Kappa co-efficient $\hat{K} = \frac{N \left(\sum_{i=1}^{r} x_{ii}\right) - \left(\sum_{i=1}^{r} (x_{i+} \cdot x_{+i})\right)}{N^2 - \left(\sum_{i=1}^{r} (x_{i+} \cdot x_{+i})\right)}$

Where;

$\left(\sum_{i=1}^{r} x_{ii}\right)$ = Number of points or pixels picked * Sum of correct points in the diagonally obtained.

$\left(\sum_{i=1}^{r} (x_{i+} \cdot x_{+i})\right)$ = Row total * Column total + Row total * Column total of each class.

Evaluation of The Effects of The Land Use Changes on The Water Extent of OkoleWetland

To evaluate the effects of the land use changes on the water content of Okole wetland, the Normalized Difference Water Index was calculated using the respective bands of the downloaded satellite images using raster calculator in Arc GIS toolbox based on the formula; **NDWI= (NIR-SWIR)/NIR+SWIR.**

For both 2010and 2015, NDWI was calculated as (Band3-Band4)/ (Band3+Band4) since the images used were Landsat 7 and Landsat 5 respectively while for 2020, NDWI was calculated as (Band4-Band5)/(Band4+Band5) since the image used was Landsat 8.

Assessment of Effects of The Land Use Changes on The Vegetation Health Status

This was done by calculating the Normalized Vegetation Index using the respective bands of the downloaded satellite images using raster calculator in Arc GIS toolbox based on the formula; **NDVI**= (**NIR** − **RED**) / (**NIR** + **RED**)

For both 2000 and 2010, NDVI was calculated as (Band4-Band3)/(Band4+Band3) since the images used were Landsat 7 and Landsat 5 respectively while for 2020, NDVI was calculated as (Band5-Band4)/(Band5+Band4) since the image used was Landsat 8.

RESULTS

Land Use and Land Cover

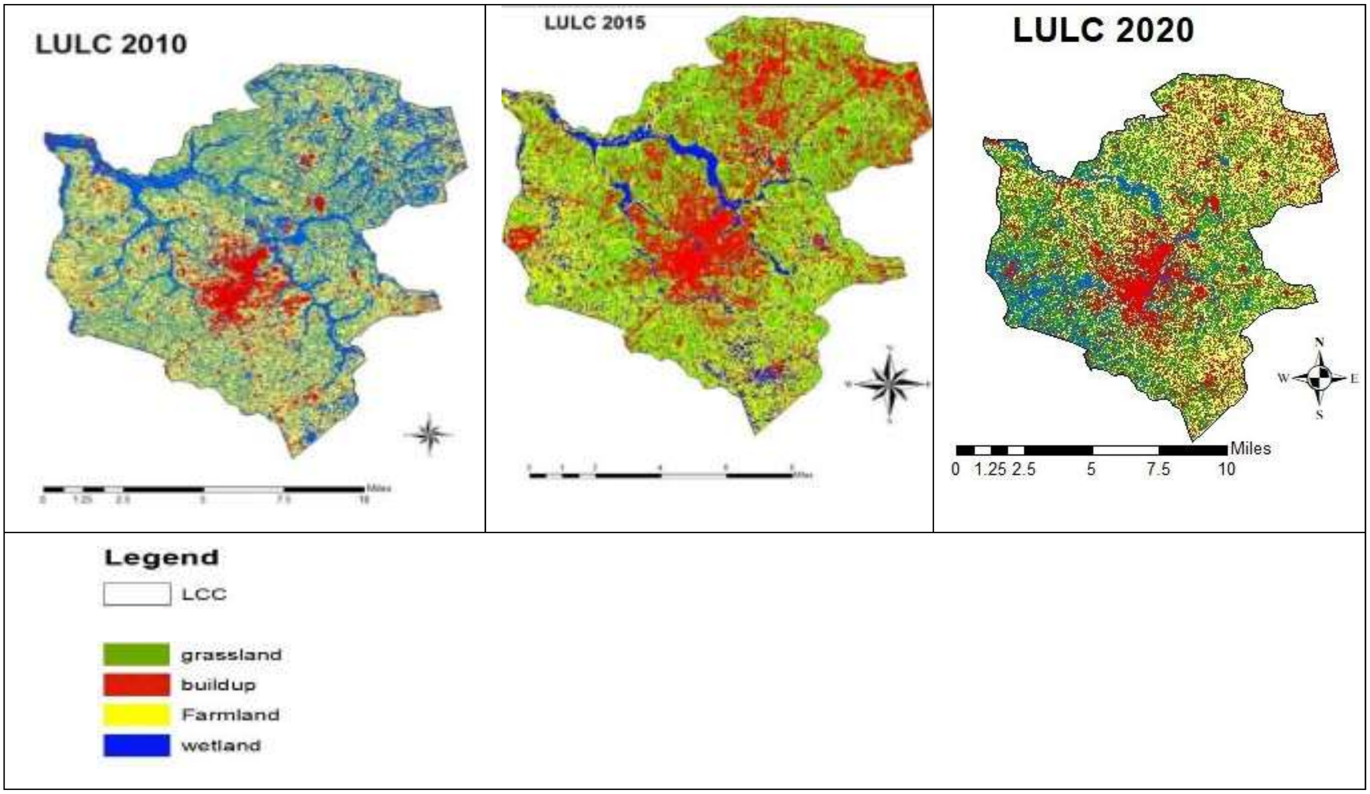

Figure 2: Land use/cover types within Okole Wetland in 2010, 2015, and 2020

Years	**2010 (km²)**	**%**	**2015 (km²)**	**%**	**2020 (km²)**	**%**
Wetland	61.35	22.3	38.3	15.7	31.4	11.4
Farmland	87.09	31.7	77.3	31.7	92.4	33.4
Buildup	97.18	35.3	92.0	37.8	103.1	37.4
Forest	29.54	10.7	36.1	14.8	49.1	17.8
Total	**275.16**	**100**	**243.7**	**100**	**276**	**100**

Table 3: Land use types and their percentage areal coverage

The Okole catchment area's land use and land cover change detection reveal that the wetland decreased by -6.6% and -6.6% for the 2010–2015 and 2015–2020 periods, respectively, while the catchment's built-up areas have grown throughout the years as well, rising from 0% and 1.7% respectively, between 2010-2015 and 2015-2020. While sparsely forested areas decreased by 4.1% and 3% between 2010-2015 and 2015-2020, correspondingly. As can be seen below, farmlands saw increases of 0% and 1.7% from 2010 -2015 and lag range increment of 1.7% from 2015 -2020. Generally, Land use land cover detection in the Okole catchment area revealed that forest, farmland and built up areas have generally increased while wetland had decreased between 2010 and 2020 as summarized in table 4 below.

Table 4: Changes in Land Use types in relation to their percentage areal coverage

Year	**Changes 2010-2015**		**Changes 2015-2020**		**Changes 2010-2020**	
Use type / land Cover	Area		Area		Area	
	Km²	%	Km²	%	Km²	%
Wetland	-23.1	-6.6	-16.9	-6.6	-29.95	-10.9
Farmland	-9.79	0	15.1	1.7	5.31`	1.7
Buildup	-5.18	2.5	11.1	-0.4	5.92	2.1
Forest	6.56	4.1	13	3	19.56	7.1

Between 2010 and 2020, The net changes between land use/cover types over different years showed that built-up areas increased (2.1%); whereas Forest (7.1%), Farmland (1.7%) and Wetland (-10.9%) decreased (Table 4). The net changes (either increase or decrease) in land use/cover types between 2010 and 2015 were not greater than those between 2010 and 2020

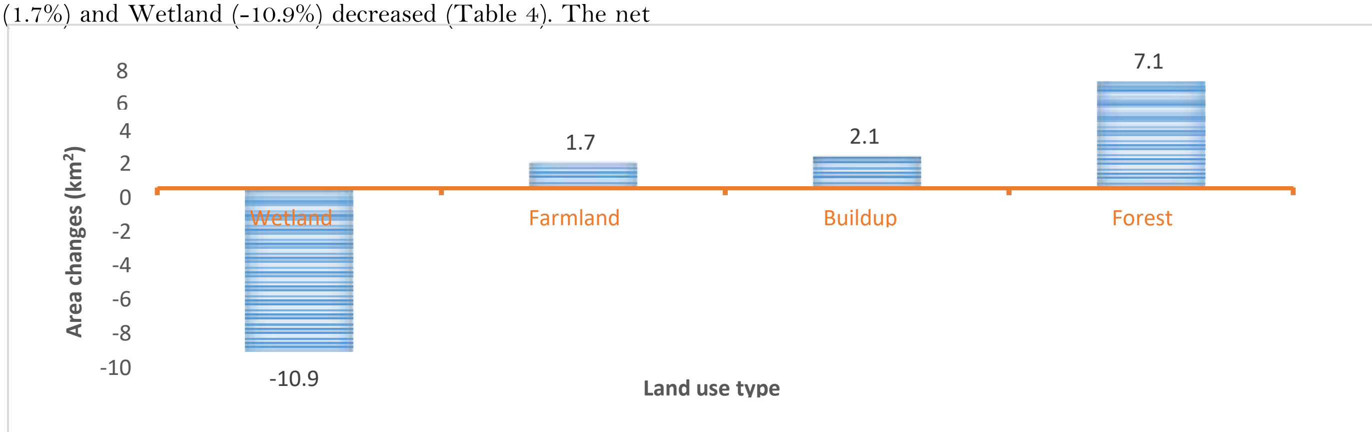

Figure 3: Land use/cover changes between 2010 -2020 Okole wetland

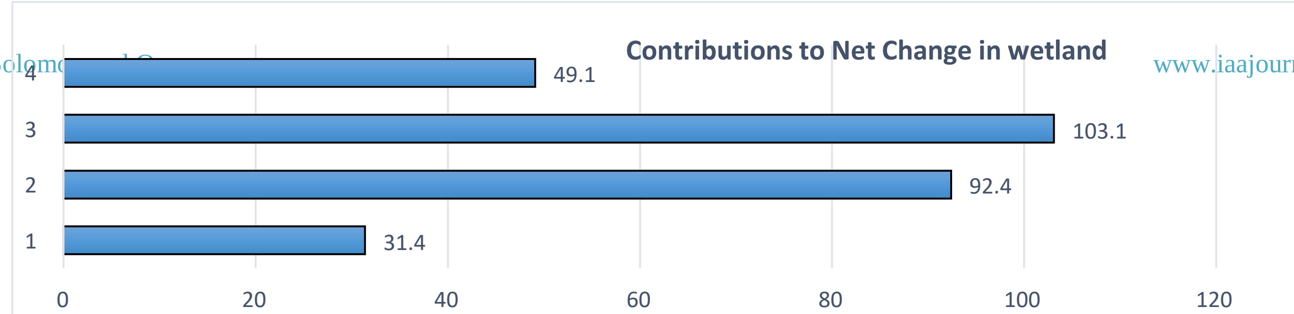

Figure 4: Land use/cover Net changes between 2010 -2020 Okole wetland.

Effects of the land use changes on the Vegetation extent of Okole wetland

The value of NDVI ranges from −1 to 1. In the maps in Figure 6, places with healthy and dense vegetation are seen in the green areas of the image (NDVI value between about 0.3to -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 2010, 2015 & 2020 NDVI Values Years Changes in NDVI values in Okole Catchment Highest NDVI Lowest NDVI 25 0.645161), orange-yellow areas indicate bare soil or dead/sparse vegetation (NDVI value between 0 to 0.29) while the red areas indicate those with no live green biomass such as water surfaces and built-up areas (NDVI value between about -0.534247 to 0). The areas with high NDVI values decreased by 11.8% in the 2010-2020 period, which means that vegetation biomass within the catchment is declining.

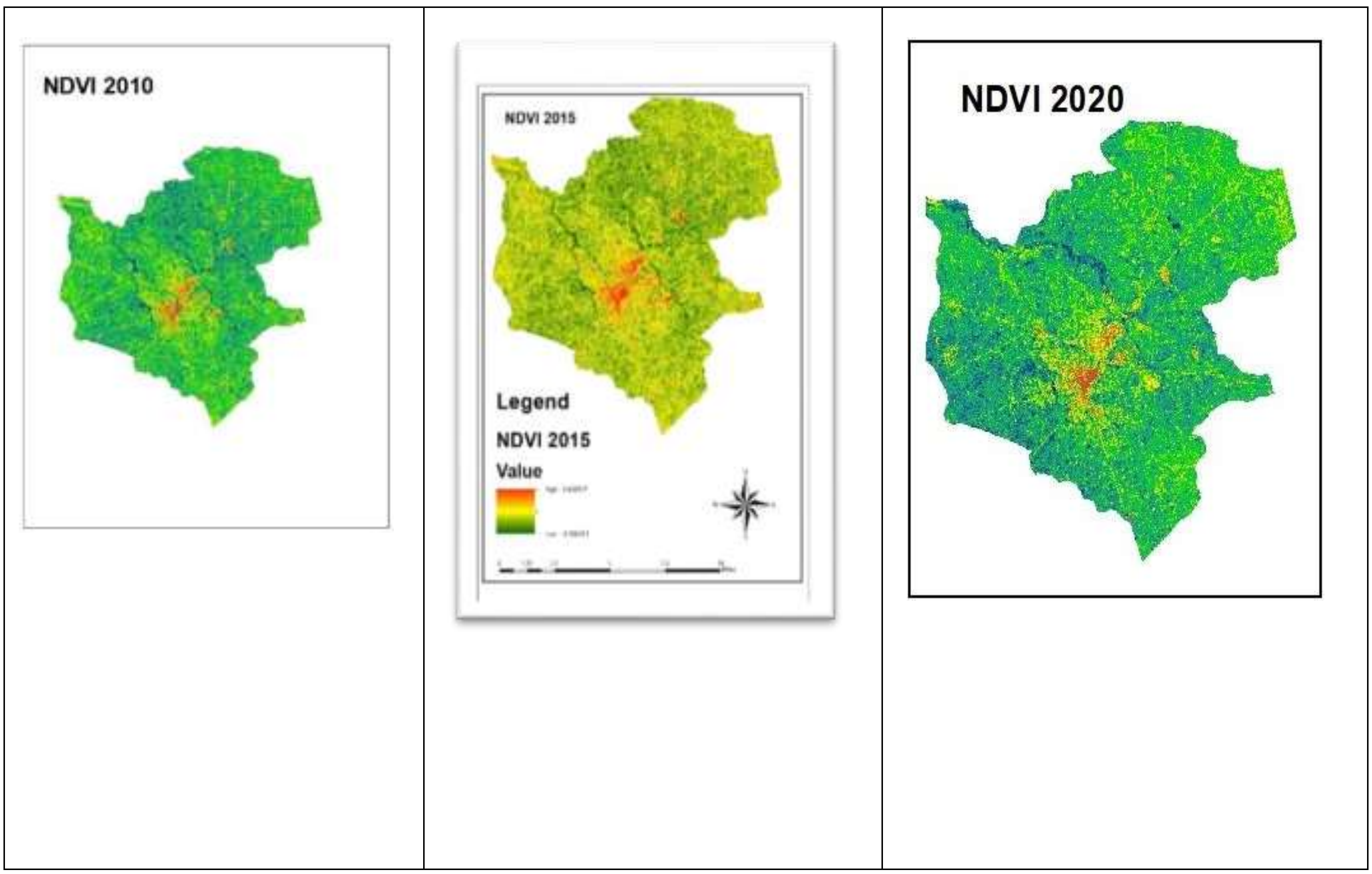

Figure 5: Effects of the land use changes on the water extent of Okole wetland

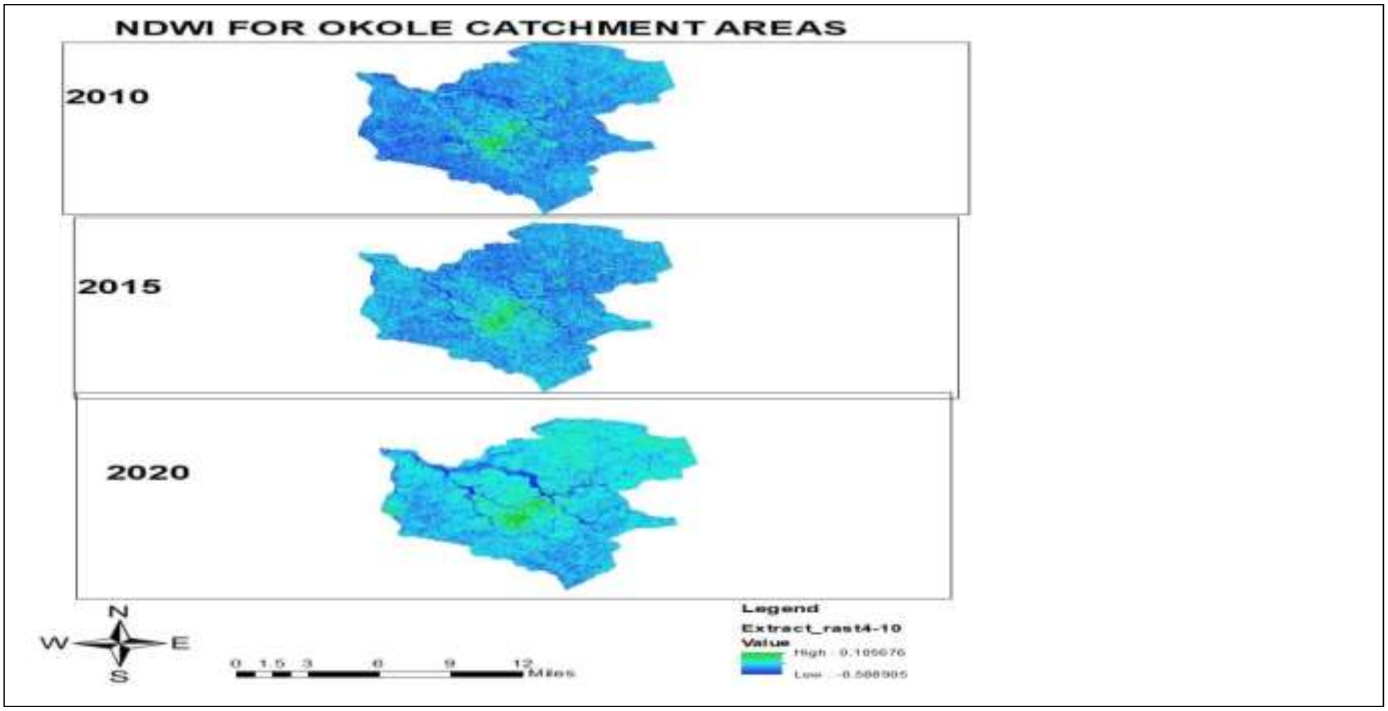

Figure 6: NDWI maps of Okole Catchment for 2010, 2015 and 2020

The value of Normalized Difference Water Index (NDWI) ranges from -1 to 1 and in this particular study, the NDWI values ≤ 0.1(areas in sky blue and green colours) represent non-water surfaces which include built-up areas, vegetation, and bare soil while those ≥ 0.1 (areas in blue colour) represent open water surfaces and wetland areas. The results of this study show that the overall highest NDWI value (0.105676) was in 2010, while the highest NDWI value in 2015 was 0.458937 and that of 2020 was -0.00707 as shown in Figure 7. The areas with a high NDWI value reduced by 58.1% between 2010 and 2020 which means the catchment is becoming increasingly drier.

DISCUSSION

The results of land use land cover analysis between 2010 and 2020 have shown significant LULC changes. The extents of land use and land cover change varied drastically over the period of study between 2010 and 2020. The most affected are wetlands, farmland, and forests which have declined over time by -10.9%,1.7%,2.1%, and 7.1% respectively. The decline in wetlands is attributed to the influence of human activities such as unsustainable agricultural practices in the wetlands compounded with infrastructural development such as roads, industries, and open dumping of debris. The finding of the study confers with the recent study [12, 13] which found out that agriculture is major threat to wetlands in Uganda and Zimbabwe. Sridharan [14] estimates that today at least 55% of the rice production of Uganda is cultivated in wetland areas (2% in irrigated wetlands and 53% in rain-fed wetlands). In agreement, this study also reported that agricultural practices in the wetlands are frequently draining and causing over-exploitation of the wetland resource [15]. Built-up areas have significantly increased by 2.1% in the study area between 2010and 2020. This increment is attributed to the high population growth rate of 4% per annum this could also be due to high influx into the urban centers by the rural communities for settlement. Built-up increase in the study areacould be due to the massive infrastructural development such as the roads. The net changes (either increase or decrease) in land use/cover types between 2010 and 2020 were greater than those between 2010 and 2022. This means that the rate of land use/cover change was higher in the first period than in the second period. This finding confers with the recent study by [16], the study found that between 2010 and 2020, there was a significant increase in Farmland (+1.7%) and built-up areas (+2.1%), Forest (+7.1%) and a significant decrease in wetland (-10.9%). This is attributedto rapid population growth, urban sprawl, infrastructure development, and commercial farming between 2010 and 2020.

However, between 2010 and 2015, the changes were less drastic: Forest increased by 4.1%, built-up areas increased by 2.5%, wetland decreased by -6.6%, Farmland generally pause at 0% defect. This is attributed to environmental degradation, Industrialization, resource harvesting (sand mining, papyrus harvest) waste disposal, farming, climate change, construction and Population These factors may have reduced the pressure on land resources or increased the awareness of land conservation. Environmental awareness and conservation 19 efforts: Increased environmental awareness and conservation initiatives might have gained traction between 2010 and 2020, leading to more efforts to protect natural habitats and restrict land use changes. This could have contributed to a decreasein net changes during this period. Between 2010 and 2020, the biggest land use land cover type transition was from "bush to built-up". This means that a substantial amount of land that was previously characterized as bushland or natural vegetation underwent significant development and urbanization, leading to the establishment of built-up areas such as cities, towns, residential, roads, civic, open spaces, commercial, and industrial zones. This result confers with the study of Hu and Nacun et al.[17], which concluded that the transition from grassland to croplands was the most land use/cover change between 1975 and 2015 in Xilingol, China. This means that a large area of bush was cleared and replaced by built-up areas. According to a study by [18, 19], this transition was mainly driven by population growth, urbanization, economic development, and agricultural expansion. The study also found that this transition had negative impacts on the environment, such as loss of biodiversity, soil erosion, water pollution, and increased greenhouse gas emissions. This transition is indicative of the rapid expansion of human settlements and infrastructure during this period. As populations grew and urbanization increased, there was a greater demand for housing, amenities, and economic activities, leading to the conversion of natural or undeveloped land into built-up areas. This process often involves deforestation and the loss of natural habitats, which can have environmental consequences such as the disruption of ecosystems, loss of biodiversity, and increased carbon emissions. The results indicate that by 2040, the majority of the study area is projected to be occupied by built-up areas, while wetlands will occupy the smallest portion. There is expected to be a decrease in the coverage of farmland, bush, and wetlands, while thecoverage of built-up areas will experience a significant increase by 2040. This means that the land use and land cover (LULC) patterns around Okole Wetland are expected to change significantly in the future, with more area being converted to urban and industrial uses and less land being available for natural ecosystems and agriculture. The finding is being supported by a study by Odongo et al. [20] and Assefa [21] which reported that built-up areas would increase by 0.7% by 2040. The study found that between 1986 and 2016, there was a significant increase in farmland (+11.9%) and built-up areas (+4%), and a significant decrease in forest (-7.9%), grassland (-4%), and wetland (-3%). The study also projected that by 2036, there would be a further increase in farmland (+5%) and built-up areas (+2%), and a further decrease in forest (-3%), grassland (-2%), and wetland (-1%). The observed land use land cover change pattern can be attributed to urbanization and infrastructure development will continue to expand in Uganda, resulting in a substantial increase in built-up areas by2040. This could be attributed to population growth, economic activities, and the need forhousing and amenities.

CONCLUSION

Between 2010 and 2020, there were notable shifts in the land cover types of the Okole watershed, with a decline in woods, grasslands, open water, and permanent wetlands and an increase in built-up areas, agricultural land, and seasonal swamps. The NDVI and NDWI readings of the watershed have dropped by 5.9% and 58.1%, respectively, suggesting a loss in the biomass of vegetation. The catchment's decreasing moisture content and biomass of plants are indicators of this deterioration.

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