remote sensing

MDPI

Article

# The Analysis of Land Use and Climate Change Impacts on Lake Victoria Basin Using Multi-Source Remote Sensing Data and Google Earth Engine (GEE)

**Maram Ali [1], Tarig Ali [2], Rahul Gawai [2], Lara Dronjak [3] and Ahmed Elaksher [4,*]**

[1] Master of Urban Planning Program, American University of Sharjah, Sharjah P.O. Box 26666, United Arab Emirates; g00095363@aus.edu
[2] Department of Civil Engineering, American University of Sharjah, Sharjah P.O. Box 26666, United Arab Emirates; atarig@aus.edu (T.A.); rgawai@aus.edu (R.G.)
[3] Department of Biology, Chemistry, and Environmental Sciences, American University of Sharjah, Sharjah P.O. Box 26666, United Arab Emirates; ldronjak@aus.edu
[4] College of Engineering, New Mexico State University, P.O. Box 30001, Las Cruces, NM 88003, USA
* Correspondence: elaksher@nmsu.edu

**Abstract:** Over 30 million people rely on Lake Victoria for survival in Northeast African countries, including Ethiopia, Eritrea, Somalia, and Djibout. The lake faces significant challenges due to changes in land use and climate. This study used multi-source remote sensing data in the Google Earth Engine (GEE) platform to create Land Use and Land Cover (LULC), land surface temperature (LST), and Normalized Difference Water Index (NDWI) layers in the period 2000–2023 to understand the impact of LULC and climate change on Lake Victoria Basin. The land use/land cover trends before 2020 indicated an increase in the urban areas from 0.13% in 2000 to 0.16% in 2020. Croplands increased from 6.51% in 2000 to 7.88% in 2020. The water surface area averaged 61,559 square km, which has increased since 2000 with an average rate of 1.3%. The “Permanent Wetland” size change from 2000 to 2020 varied from 1.70% to 1.83%. Cropland/Natural Vegetation Mosaics rose from 12.77% to 15.01%, through 2000 to 2020. However, more than 29,000 residents were displaced in mid-2020 as the water increased by 1.21 m from the fall of 2019 to the middle of 2020. Furthermore, land-surface temperature averaged 23.98 degrees in 2000 and 23.49 in 2024.

**Keywords:** MODIS; Sentinel-2; Landsat 7 ETM+; LULC; NDWI

check for updates

**Citation:** Ali, M.; Ali, T.; Gawai, R.; Dronjak, L.; Elaksher, A. The Analysis of Land Use and Climate Change Impacts on Lake Victoria Basin Using Multi-Source Remote Sensing Data and Google Earth Engine (GEE). *Remote Sens.* **2024**, *16*, 4810. https://doi.org/10.3390/rs16244810

Academic Editors: Eugene Levin, Roman Shults and Surya Prakash Tiwari

Received: 29 August 2024
Revised: 11 October 2024
Accepted: 18 October 2024
Published: 23 December 2024



## 1. Introduction

Lake Victoria is the largest freshwater lake in Africa and tropical zones and the second largest freshwater lake in the world; the largest one is Lake Superior in North America [1], with a 194,200 square kilometers catchment area of the basin [2,3], and a lake water surface area of around 69,295 square kilometers [4,5]. Lake Victoria (LV) is inhabited by 30 million people, which is considered Africa’s highest population density [6,7]. Its diverse ecosystem supports millions of lives through agriculture, water supply, and livelihoods [1], especially the fish [3]. It is located between the Central African and East African Rift valleys, spanning the equator (0°30′N–3°12′S; 31°37′–34°53′E) [8]. Furthermore, The Lake Victoria Basin (LVB) is a crucial ecological, socio-economic, and cultural center in East Africa, shared by Uganda, Kenya, and Tanzania. However, Tanzania has the largest percentage of shoreline (Figure 1); this wide body of water stretches into the horizon—appearing more like an ocean than a lake [8]. At the same time, the Lake Basin is located in five countries: Tanzania, Uganda, Kenya, Rwanda, and Burundi, with different share percentages (Figures 2 and 3). Moreover, the Lake is a significant and critical water source for Ethiopia, South Sudan, Sudan, and Egypt [3].

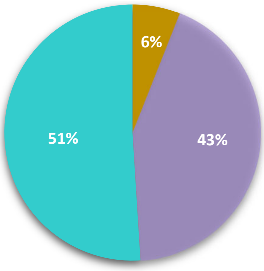


**Figure 1.** The percentage of shoreline length by country.

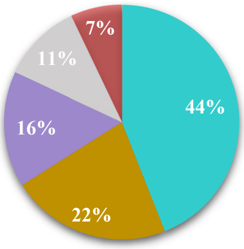


**Figure 2.** Lake Victoria Basin countries share percentages of areas.


**Figure 3.** Lake Victoria's hydrological and geographical settings [9].

Lake Victoria depends on rain for 80% of its water [8], with the remaining 20% coming from the Kagera, Mara, Ngono, Grumeti, and Simiyu rivers [Table 1]. Lake Victoria, which has experienced three complete dry-ups over the past 100,000 years, has been replaced by vast grasslands on each occasion. The Lake is an important area with both economic and ecological significance. However, it is currently under threat due to significant regional development and urbanization that has taken place over the years. This has caused changes in land use and land cover (LULC), as well as contributing to global environmental changes such as climate change. As the lake's existence is strongly related to the rainfall, which makes it highly susceptible to changes in climate and land use of the Lake Victoria Basin, observable alterations in rainfall patterns, temperature fluctuations, and the frequency of extreme weather events have posed considerable threats not only for the lake water but all ecosystem in the basin area [10]. While the climate change resulted from the change in the LULC and affects vegetation and soil factors [11,12], these transformations in land use and land cover, driven by population growth, urbanization, agriculture expansion, and deforestation, have significantly altered the basin's landscape, influencing its hydrology, biodiversity, and overall ecological equilibrium [13,14].

**Table 1.** Water resources for Lake Victoria.

| Water Source for Lake Victoria | Water Amount [$m^3$/Day] | Percentage [%] |
|---|---|---|
| Rainfall | 193,920,000 | 80 |
| Kagera River | 32,408,880 | 13.37 |
| Mara River | 7,200,000 | 2.97 |
| Ngono River | 3,878,400 | 1.60 |
| Grumeti River | 2,884,560 | 1.19 |
| Simiyu River | 2,302,800 | 0.95 |
| Total Lake water | 242,594,640 | 100 |

Up until 2019, understanding the history of the lake was crucial in identifying patterns of change to prevent it from drying up [15]. However, in June 2019, the water level of Lake Victoria began to rise rapidly due to an increase in rainfall. As of June 2023, the average water level is 13.42 m, which is the highest recorded in the Lake's history. In 2019, the water levels were at 12.00 m, according to the East Africa Consortium for Clinical Research [14]. The highest recorded flood levels exceeding 13.41 m were in 1964. This has resulted in most of the buildings in the lake basin being displaced. Currently, Kenya is constructing three dams to control floods, while environmentalists are working with farmers to prevent soil erosion [15]. In the period between April and July 2020, over 29,000 people residing within a 50 km radius of the Lake's shorelines were impacted by floods. The Basin experienced the highest levels of precipitation in at least three decades, leading to a 1.21 m rise in lake levels from late 2019 to mid-2020. This flood event is classified as a 63-year event in the current climate, defined as a six-month rise in lake levels as extreme as that observed in the lead-up to May 2020 [16].

It is crucial to monitor the challenges and significant changes in the lake and its basin due to their environmental, social, and economic impacts on Northeast Africa [4]. Over 30 million people and 334 species [16] rely on the lake's resources, which are vital in agriculture, livelihoods, the blue economy, and water. However, land use and climate change pose a significant threat to the lake's water security. Additionally, the unexpected rise in water levels in 2020 caused environmental and economic disasters. This paper aimed to explore these challenges and analyze patterns of change in land use and water levels before and after 2020. The findings will guide better land use planning programs, strategies, and policies to adapt to future climate change impacts.

This article discusses two main concerns related to Victoria Lake's water, which are land use and land cover changes affecting water quality and the rise in water levels affecting land use in the basin. The paper analyzed existing research on Victoria Lake's water quality assessments and highlighted the correlation between these assessments and changes in land use and land cover over the years. Furthermore, this study focused on the water levels in the lake over the past 32 years at six-month intervals, comparing the effects of increased water levels since 2019 on land use and land cover in the Lake Victoria Basin (LVB).

## 2. Methodology

The methodology, which is carried out within Google Earth Engine (GEE), involved obtaining, pre-processing, and processing multi-sensor satellite imagery, including 500 m resolution MODIS data, 20 m Sentinel-2 data, and 30 m Landsat 7 ETM+ data. Google Earth Engine (GEE) is a freely accessible platform that provides access to satellite remote sensing data and spatial analysis tools [17–19]. GEE supports cloud-based processing and allows for coding for data extraction and processing. Moreover, GEE has a rich stack of API documents, many remote sensing image processing algorithms, and a user-friendly interface.

### *2.1. Moderate Resolution Imaging Spectroradiometer (MODIS) Data*

The LULC data layers were extracted for the study area in GEE from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) data, combining information from the two MODIS instruments, Terra and Aqua. Specifically, the data layers were extracted from the NASA LP DAAC at the USGS EROS Center's product, MCD12Q1v061, which has a 500 m resolution and is derived through supervised classifications of MODIS reflectance data [20].

The land surface temperature (LST) data layers were extracted from MODIS thermal bands 31 and 32. Specifically, the data layers were extracted from the NASA LP DAAC at the USGS EROS Center's product, MOD11A1.061, which has a 1 km resolution in which temperature value is derived from the MOD11_L2 swath product.

### *2.2. Sentinel-2 & Landsat 7 ETM+*

Sentinel-2 is the European Space Agency's (ESA) high-resolution, multi-spectral imaging. In this study, Level-2 20 m resolution data were accessed and processed in GEE to produce a robust boundary of Lake Victoria; Sentinel-2 data were used to derive the water index, specifically the Normalized Difference Water Index (NDWI). The NDWI is known to capture the spectral characteristics of water, enabling the difference between water and other land surface features [21]. Using Sentinel 2 data, the NDWI can be calculated using Equation (1).

$$\text{NDWI (sentinel 2)} = (\text{band 3} - \text{band 8})/(\text{band 3} + \text{band 8}) \tag{1}$$

Equation (1) was implemented in GEE to extract the lake's water boundary in 2020 and 2023. Sentinel-2 data for the study area were first pre-processed using cloud masking and radiometric calibration. Radiometric calibration converts the digital number (DN) to the top of the atmosphere (TOA) reflectance. Pre-processing was concluded with atmospheric correction of the imagery using the ESA's sen2cor tool for Sentinel-2 imagery processing [22]. Sentinel-2 bands we used to estimate the NDWI (Equation (1)) are Band 3: Green (0.543–0.578 µm) and Band 5: Near-Infrared (0.785–0.899 µm). The NDWI data layers were derived in GEE and then imported into ArcGIS Pro as raster layers, which were reclassified and converted to polygon layers.

Collection 2 surface reflectance Tier 1 data, which are atmospherically corrected, were used to estimate NDWI in 2000, 2005, 2010, and 2015. Specifically, the Enhanced Thematic Mapper Plus (ETM+) sensor data were used to calculate NDWI using Equation (2).

$$\text{NDWI (Landsat 7 ETM+)} = (\text{band 3} - \text{band 5})/(\text{band 3} + \text{band 5}) \tag{2}$$

Landsat 7 is USA NASA's high-resolution, multi-spectral imaging satellite that carries the Enhanced Thematic Mapper Plus (ETM+) sensor. Landsat 7 ETM+ imagery has seven spectral bands (30 m) and a panchromatic (15 m). The Landsat 7 ETM+ bands we used to estimate the NDWI (Equation (2)) were Band 3: Red (0.63–0.69 µm) and Band 5: Short-wave Infrared (1.55–1.75 µm).

## 3. Results and Discussion

### *3.1. Qualitative Change in the Lake Water*

The change in the patterns of land use, mainly linked to agricultural practices and urban development, has been identified as a potential contributor to water quality issues [23–25]. The decrease in watersheds and changes in land cover have implications for Lake Victoria's variability in chlorophyll-a and turbidity concentrations [20]. About 75% of the wetland area in the Ugandan Victoria Lake Basin has been significantly affected by human activities, and about 13% was severely degraded from 1980 to 2015 [26]. During the 1990s, there were very high perceptions of chlorophyll-a concentrations compared with the measurements taken in 2018–2019. This level of chlorophyll-a suggests that there have been changes in nutrient dynamics and phytoplankton dominance. In 2023, the lake's phytoplankton will still be mostly dominated by diatoms and cyanobacteria. However, taxa have shifted from gas-vacuolated heterocystous to non-heterocystous filamentous and coccal/colonial cyanobacteria [27]. However, in 2019, some parameters, such as Biochemical Oxygen Demand, Phosphorus, Lead, and Cadmium, showed slight improvements from the 2013 sampling. However, Nitrogen levels slightly increased and may have come from agricultural fertilizers, wastewater, and animal waste [28]. In the same year, 2019, chlorophyll-a weight percentage was measured in the surface waters of the Lake. The concentration found in shoreside waters was $10.3 \pm 7.1$ μg/L, while in offshore waters, it was $2.8 \pm 1.1$ μg/L. This concentration suggests that the current levels are lower than those observed in the 1990s. Changes in the Lake's phytoplankton composition and higher dissolved silica concentrations were also observed. The recent modifications have resulted in the return of Aulacoseira spp. to the Lake [19]. In the 2020s, Lake Victoria's ecosystem is under threat due to pollution. Traditional pollutants, such as nutrients, contribute to algae's growth and oxygen depletion in the Lake. In addition, emerging pollutants like microplastics [Polyethylene and Polypropylene] [29], pharmaceuticals, and e-waste are worsening the problem. Human activities such as washing clothes and bathing in the Lake contribute to nutrient pollution, and sand mining disrupts fish breeding areas. The microplastics found in fish pose a health risk, and the decline in fish stocks puts the economic livelihoods of communities surrounding the lake in danger [30].

### *3.2. Change in Landuse/Landcover (LULC) Patterns*

Land use refers to how humans use and manage land and its resources to sustain life [31]. It encompasses any human activity related to land use for agricultural, residential, commercial, or other purposes. The reasons for land use and land cover change are often a combination of human and natural events [32]. Land cover, on the other hand, refers to the physical and biological materials on the land's surface, whether they are natural or human-made. This is different from land use. Land use and land cover are commonly used together as (LULC), which is considered the result of natural and socio-economic aspects of an area and their corresponding human activity in space and time [33]. Land use and land cover change (LULCC) have increased within basin boundaries [34] and globally due to a variety of biophysical, political, and socio-economic factors [9,35]. Some studies have suggested that the complex interactions of these factors, combined with population pressure and technological advancements, lead to LULC change [1,28–37]. Over the past 30 years, the Victoria Lake basin has featured different types of natural forests, croplands, water bodies, bare lands, urban areas, and other activities.

Kenya experienced a remarkable increase of 500% in production values between 1985 and 1990. In recent years, research on pollution in the Lake Victoria Basin has gained prominence. It has been actively conducted by institutions such as the University of Nairobi and the Kenya Marine and Fisheries Research Institute (KMFRI) [36]. Similarly, Tanzania saw a substantial increase in production values by 750% during the same period. Meanwhile, flooding has become a critical issue in Uganda, leading to the displacement of a majority of the basin's residents and highlighting the urgent need for mitigation measures [38]. Over the years, the entire Lake Victoria Basin's LULC has undergone significant changes from 1901 to 2019. Concerns have been raised about reducing vegetation cover and expanding urban and industrial land use zones, which have affected water quantity and quality [2,38]. However, since 2020, the primary concern has shifted to the dangers posed by a significant decrease in urban areas.

The high population growth before 2020 in the LVB in recent decades has led to deforestation, the removal of grass, and the expansion of agriculture and urbanization [30,39]. A massive volume of the literature looks at the LULC cover change before the floods and the rise in the Victoria Lake water level; all used remote sensing. Landsat imageries have critically served the classification of the different urban and environmental components in screening for land use land/cover change [30]. The focus is mainly on the riparian areas [40], aiming to know about the LULC patterns in those areas, how they change, and the impact of those changes. In the Ugandan part of the LVB, between 1955 and 1985, only 33 square kilometers (1.3%) of the total terrain was converted to subsistence farming. Secondly, between 1955 and 2000, 48 square kilometers (2.0%) of the whole terrain were converted to subsistence farming. Only 15 square kilometers (0.6%) of the total terrain was converted to subsistence farming between 1985 and 2000. The highest elevation areas in the Kenyan Part of the basin are primarily used for grazing. In contrast, the canyon floor is used for cultivation, except for flooded areas. Homesteads are distributed by altitude, separating cultivation fields down the valley and grazing fields up the hills [41].

The Kenyan part of the LVB is divided into five counties (Busia, Homabay, Kisumu, Migori, and Siaya) and was evaluated for the years 1978, 1988, 1998, 2008, and 2018. The accuracy of the evaluation was from 0.81 to 0.96, with Kappa coefficient values decreasing between 0.62 and 0.91 [42]. Significant changes have occurred in Kenya's green patterns (NDVI) [6]. Most grasslands and vegetation bays are constantly being converted to other land uses, transforming many green lands into bare lands [39,40]. This transformation is mainly due to deforestation, urban sprawl, and grass bush-burning activities [43,44]. Grasslands and vegetation growing on wetland sides are at a very high risk of dying due to decreased water levels, which was the case in the 1970s and 1980s [45], or due to high rainwater perceptions, which was the case in 2005 [46]. Another valid reason for decreasing the green cover is the removal of green lands for agricultural and residential expansion to mitigate the increase in the area's population.

In contrast, the green cover could increase when the water returns to it is average level before the flooding period. It stimulates the greeneries to grow very fast in those areas, such as the case in Nyando of Kisumu Bay [47]. Moreover, the government introduced forest plantations for water reservation in Gwassi and Wire Hills [48].

The conversion of land use is determined according to the dimension of the topography and current sub-surface. The dominant change applies agribusiness growth at the cost of grazing land. Before 1950, semiarid and sub-humid regions were primarily rural, with disorganized territories. Since the 1950s, LVB in the Kenyan area has faced a massive transformation from grazing land to diverse crop-livestock agriculture. The speed of farming growth is hindering in particular locations, especially in territories encountering a shortage of water issues, for example, below Mt. Kilimanjaro on both the Kenyan and Tanzanian sides and the eastern inclines of Mt. Kenya. Rustic inhabitant development is also decelerating in multiple locales. Nevertheless, agricultural expansion and local industries continued rapidly in some spots in Uganda, especially between 1984 and 2015 [49,50]. Looking at the Lulc change with the primary rivers' basin of the LV, for example, in the Kagera Basin, vast shifts in land cover have happened throughout the previous century. The changes are the following:

- A noteworthy boost in farmland zones occurred from 1901 to 2010, while overgrown woodlands declined considerably;
- Forests (51% to 6.9%) from 1901 to 2010;
- Savannas (35% to 19.6%) from 1901 to 2010.

Woodland degradation was monitored through 1974 and 1995 and tracked by regrowth in 1995 and 2010 because of conservation efforts. Forestation enterprises guided to an expansion in greening the forests through the exact time. The surveyed speeds of LULC change in the Kagera Basin exceed those documented in Sub-Saharan Africa and additional international territories [26,27]. In addition to the Kagera River Basin, in 2000, the Nyando River in the Lake Victoria drainage basin experienced a 16% increase in peak discharges across all 14 sub-catchments, which led to a 10% increase in the grasslands on the river sides from 5% to 15% as a result of flooding [26].

### *3.3. LULC Change Impact on the Victoria Lake Water Surface Area*

Analyzing the patterns of LULC change in the LVB is very important as it directly affects the water of the lake. Some studies conducted in the LVB revealed a strong correlation (r = 91.3%, $p$ = 0.001) between human activities and LULC changes [51]. Utilizing Google Earth data, this research brief examined the LULC change in Landsat imagery from 2000 to 2020 (Figure 4), with five-year intervals to look at the modifications in the changes in the LULC with the relationship with watershed surface area. The 15 land use and land cover categories used in this analysis are shown in (Table 2). It is noticeable from (Figure 5) that there was a change in the LULC. Changes in the LVB indicate different tendencies from 2000 to 2020.

**Table 2.** LULC classes definition in LVB.

| **LULC Classes** | **Definitions** |
|---|---|
| Evergreen Needleleaf Forests | Dominated by evergreen conifer trees (canopy > 2 m). Tree cover > 60%. |
| Evergreen Broadleaf Forests | Dominated by evergreen broadleaf and palmate trees (canopy > 2 m). Tree cover > 60%. |
| Deciduous Broadleaf Forests | Dominated by deciduous broadleaf trees (canopy > 2 m). Tree cover > 60%. |
| Mixed Forests | Dominated by neither deciduous nor evergreen (40–60% of each) tree type (canopy > 2 m). Tree cover > 60%. |
| Closed Shrublands | Dominated by woody perennials (1–2 m height) >60% cover. |
| Open Shrublands | Dominated by woody perennials (1–2 m height) 10–60% cover. |
| Woody Savannas | Tree cover 30–60% (canopy > 2 m). |
| Savannas | Tree cover 10–30% (canopy > 2 m). |
| Grasslands | Dominated by herbaceous annuals (<2 m). |
| Permanent Wetlands | Permanently inundated lands with 30–60% water cover and >10% vegetated cover. |
| Croplands | At least 60% of the area is cultivated cropland. |
| Urban and Built-up Lands | At least 30% impervious surface area, including building materials, asphalt, and vehicles. |
| Cropland/Natural Vegetation Mosaics | Mosaics of small-scale cultivation 40–60% with natural tree, shrub, or herbaceous vegetation. |
| Barren | At least 60% of the area is non-vegetated barren (sand, rock, soil) areas with less than 10% vegetation. |
| Water Bodies | Permanent water bodies cover at least 60% of the area. |

Grasslands always maintain a consequential presence, varying from 35.6% in 2000 to 38.86% in 2020, revealing ongoing power (Figure 5). Water bodies, constituting roughly 25.5% of the entire basin, are significant and regular. Evergreen Broadleaf Forests have a declining tendency, from 2.05% to 1.65%, from 2000 to 2020, respectively. Woody Savannas and Savannas present a considerable extent, with Woody Savannas encountering a slight boost from 0.59% to 0.70% in 2000 and 2020, respectively. Closed and Open Shrubland areas display instabilities, though they stay reasonably low. Permanent Wetland areas remain stable, going from 1.70% to 1.83%, and Croplands indicate take-ups, notably growing from 6.51% in 2000 to 7.88% in 2020. Urban areas and built-up land continuously grew from 0.13% in 2000 to 0.16% in 2020, demonstrating urbanization movements. Secular shifts attended in the different classifications emphasize the vibrant character of LULC. The growth in croplands and urban/built-up land underlines the continuing effect of human activities.

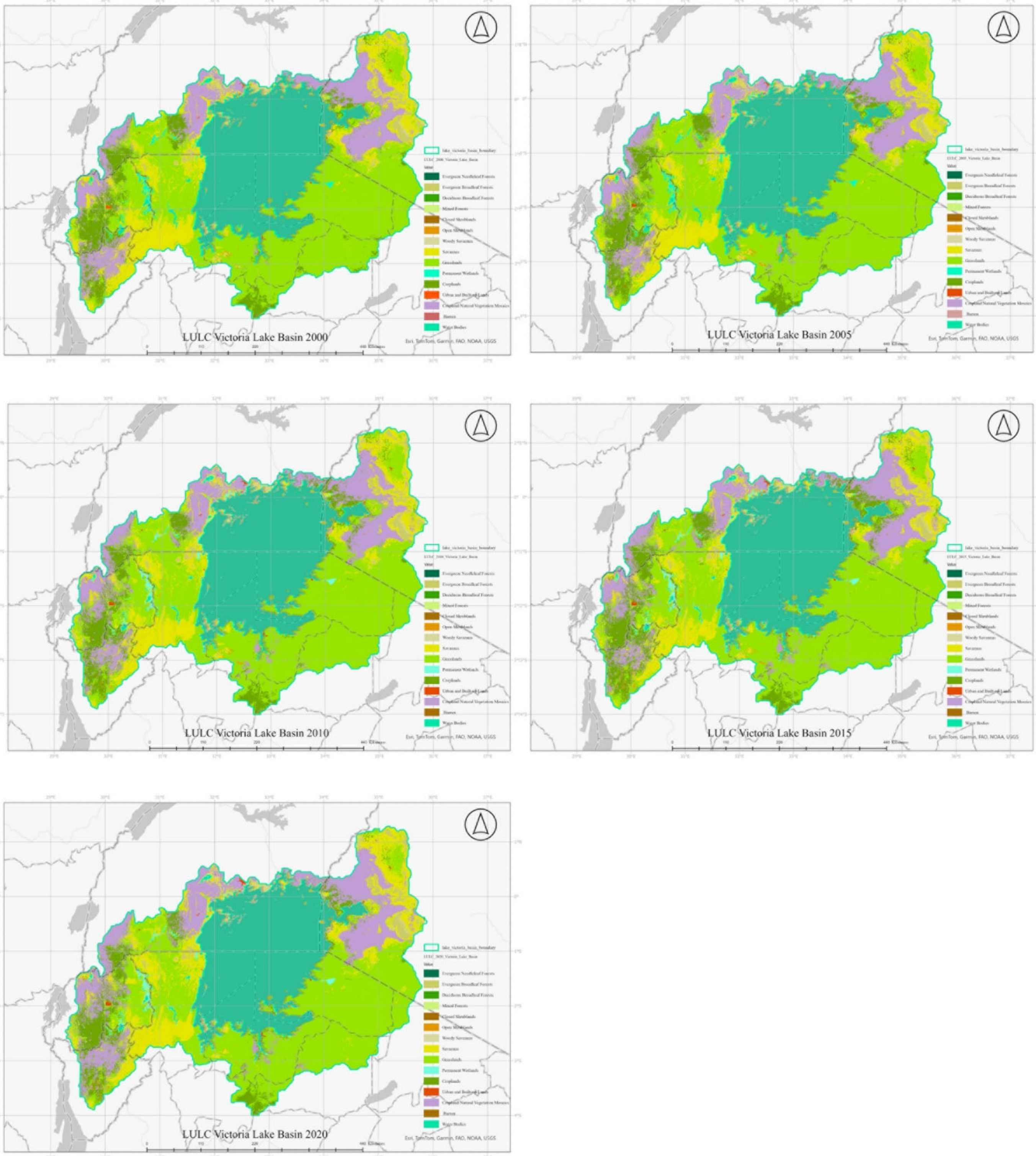


**Figure 4.** Land use and land cover change in the LVB, 2000–2020.

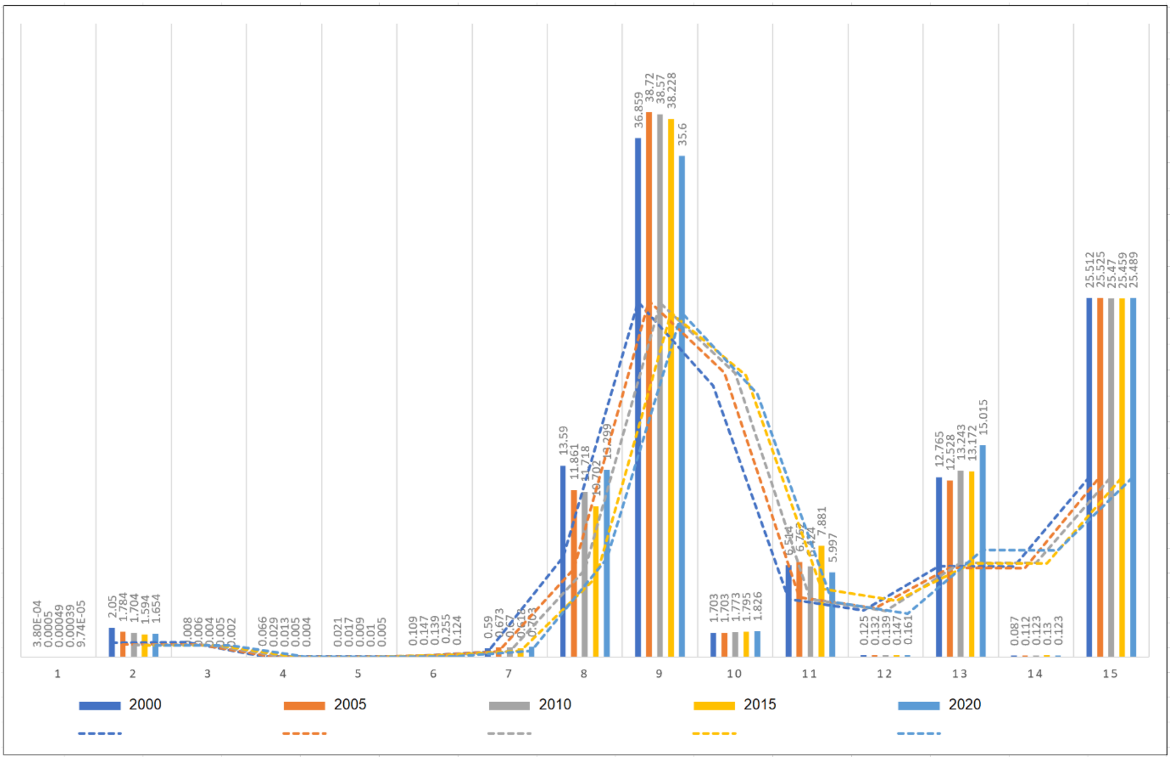


**Figure 5.** LVB Land use and land cover patterns change in percentage, 2000–2020.

The "Permanent Wetland" size displays resilience over the monitored time (2000 to 2020), varying from 1.70% to 1.83% (Figure 5). These percentages indicate possible correlations with other LULC classes. Notably, there is a positive connection with the "Water Bodies" class, as wetlands are usually related to Victoria Lake. The uniform and regular area of "Permanent Wetland" may negatively relate to "Urban and Built-up Lands", offering thriving preservation measures as wetlands are generally rescued from urban growth. The relations with classes such as grasslands, savannas, croplands, and cropland/natural vegetation mosaics could be complicated and affected by lake hydrological and environmental parameters. In general, the almost steady amount of water in the lake area suggests a slight change over the years; this change would be evident if the observed period were more than 20 years.

### *3.4. Climate Change Impact on the Victoria Lake Water*

Lake Victoria faces many environmental changes, and different characteristics contribute to the marked differences in water quantity [52]. Over the past four years, significant environmental changes have occurred in LV, mainly attributed to changes in land use and land cover, inappropriate agricultural practices, industrialization, and the degradation of critical water bodies, among other factors [22]. Currently, the main concern since May 2020 has been the geographical expansion of the lake's water area. By using remote sensing, the floods were mapped, indicating that more than 29,000 inhabitants in the 50 km buffer of the lake boundaries were influenced by the recorded floods between April and July 2020 [8]. LVB suffered from the unpredicted rise in water precipitation levels, driving the water level to increase by 1.21 m from the fall of 2019 to the middle of 2020. This flood record happened 63 years ago [22].

Lake Victoria faced a critical increase in water level beginning in October 2019. The levels reached 12.66 m in December 2019 and reached their maximum at 12.94 m on 6 May 2020. the lake's water volume increased by approximately 1750 gigatonnes over the study period from 2019 to 2020 [49]. That huge water volume change impacted the hydraulic forces in energy generation stations, leading to damage to dams [53]. Consequently, approximately

200,000 individuals living around the lake have been replaced or left without homes [8]. Furthermore, different developments such as recreational facilities, agricultural lands, and residences around LV and the River Nile were flooded and affected the local economy [26].

Many pieces of literature (e.g., [39,54,55]) and online sources show that the LV water level [Figure 6] faced hydrological dynamics over the past 32 years between January and June. In the 1990s, the water levels were relatively stable at around 1135 m. In the 2000s, the data show varying levels, with some years experiencing slight decreases or moderate increases. There were significant upraises in 1998 and 2000, gaining 1136.5 and 1136.21 m respectively. In the last years, an incremental upward tendency has been noticed, with 2020 and 2021 records where the most increased water levels reached 1136.81 and 1136.8 m, respectively. In January 2024, the level was decreased slightly to 1136.47 m.

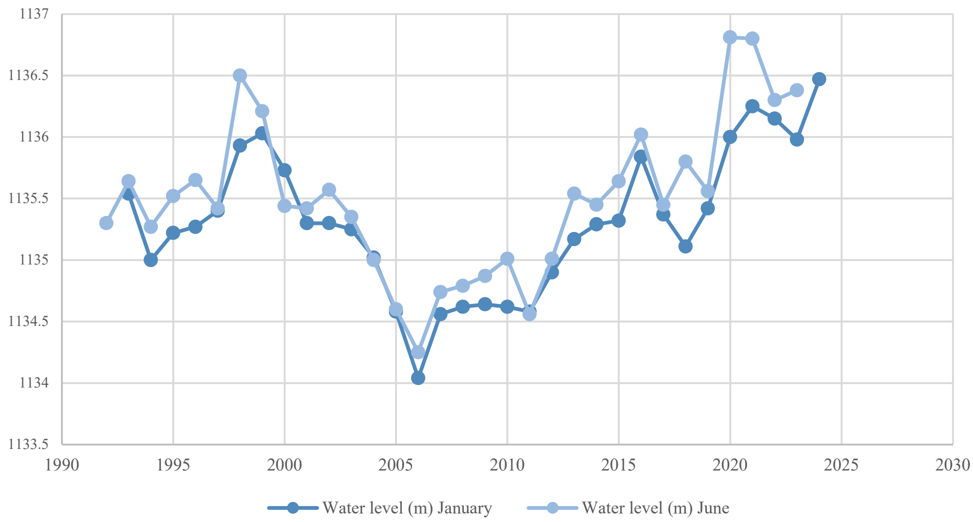


**Figure 6.** The change in water level in Victoria Lake from 1992 to 2024 (https://hydroweb.theia-land.fr/hydroweb/view/L_victoria?lang=en(accessed on 18 March 2024)).

The expectation of the climate analysis and the collected information reveals that severe circumstances, such as the considerable peak in water levels from the last of 2019 to the middle of 2020, have 1.8 times more potential in the recent climate because of human activities. Without such an effect, a similar case would have resulted in a more than 7 cm inferior peak in VL water quantity [53,56]. However, natural variability contributes to uncertainties in the parameters statement, increasing the chance that the possibility or magnitude of the marked changes may not be directly attributable to anthropogenic environmental impact.

Water management can cause floods and increase water levels even after flood season. The susceptibility of the built environment, the local businesses in the flooding zones, and the ways in which climatic variables impact seasonal rainfall play significant roles [57]. The increase in water quantity has consequences that go beyond just climate-related stress. Energy generation companies have reported that the gradual rise in water levels is affecting source levels in Nalubaale and Kiira energy generation stations. This, in turn, affects the hydraulic pressures and leakage pipes in the dams. This illustrates the interplay between natural environmental changes and man-made structures, emphasizing the need for a comprehensive understanding of their relationship.

The Intergovernmental Panel on Climate Change (IPCC) studies various aspects of climate change and emphasizes Africa's vulnerability to global warming, which is predicted to exceed international standards. In particular, regions like the White Nile River, which is a major source of water for Lake Victoria, are expected to experience changes in precipitation levels, adding to the complexity of environmental challenges faced by the region [58]. LULC differences appear as key factors to environmental shifts in the LVB. Scholars highlight the complicated link between land surface procedures and climate [59], acknowledging that LULC changes [60], for example, deforestation and urbanization, cause an increase in land surface temperature (LST), while the rise in the water level as the result of flooding decreases the (LST), indicating regional climate patterns. Analysis was performed for the LST every January 2000, 2005, 2010, 2015, 2020, and 2024 using the Google Earth data source [Figure 7].

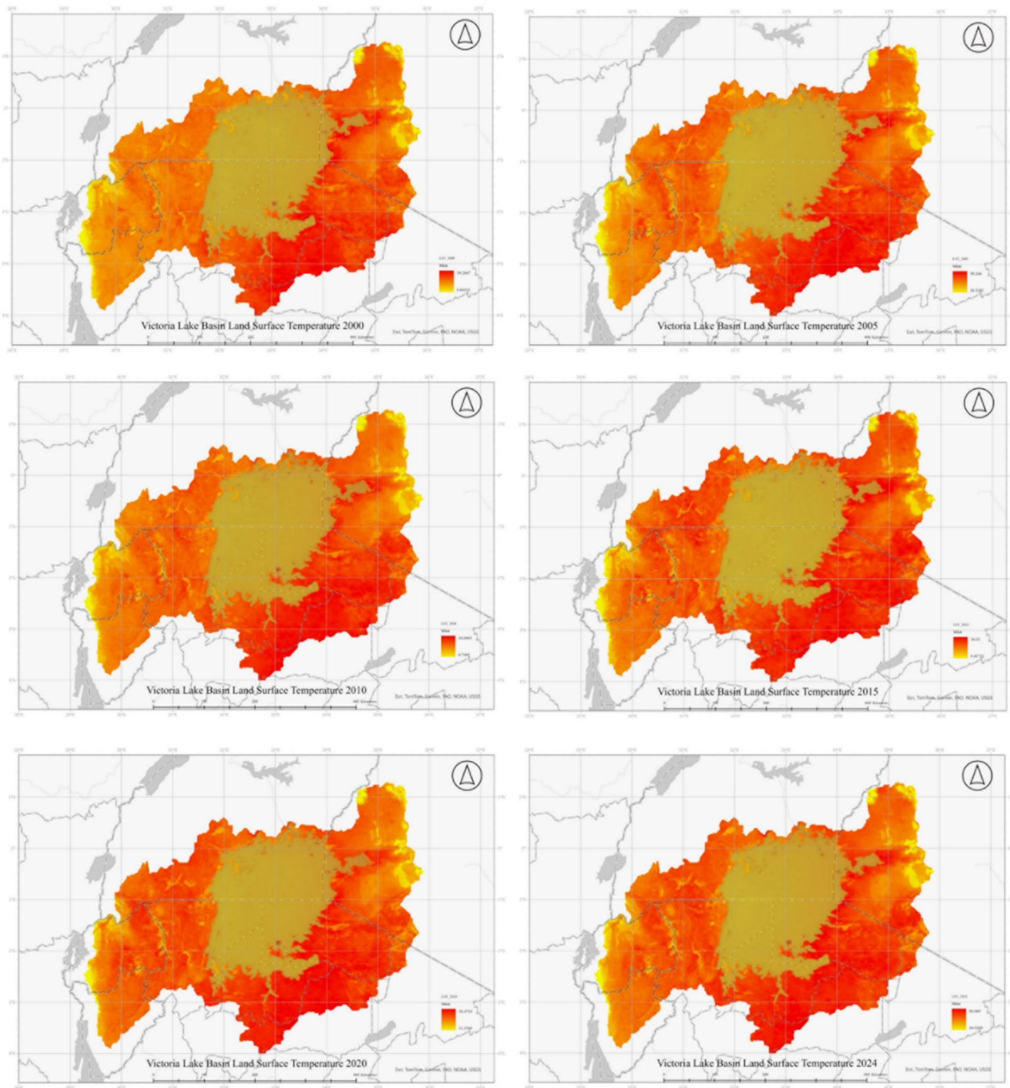


**Figure 7.** The land surface temperature change in the LVB in 2000, 2005, 2010, 2015, 2020, and 2024.

The six LST layers shown in Figure 7 above have been presented in the line graph (Figure 8), showing an essential understanding of spatial variability of LST in the last 24 years with 5-year intervals. In 2000, the LST varied from 39.2867 to 8.665 degrees, averaging 23.97585 degrees. The following years indicate instabilities, with 2024 displaying the highest temperature of 36.069 degrees, a minimum of 10.92 degrees, and an average of 23.4945 degrees. The decrease in maximum temperature in 2020 and 2024 may be due to increased water levels from flooding. Figure 9 below shows the lake's boundary presented in ArcGIS Pro as polygon layers obtained by converting the NDWI raster layers extracted from Sentinel-2 and Landsat 7 ETM+ imagery. The 2000, 2005, 2010, and 2015 NDWI raster layers were derived from Landsat 7 ETM+ imagery, and the 2020 and 2023 NDWI layers were extracted from Sentinel-2. The NDWI layers extracted from Landsat were resampled at 20 m resolution to match the resolution of those derived from Sentinel-2.

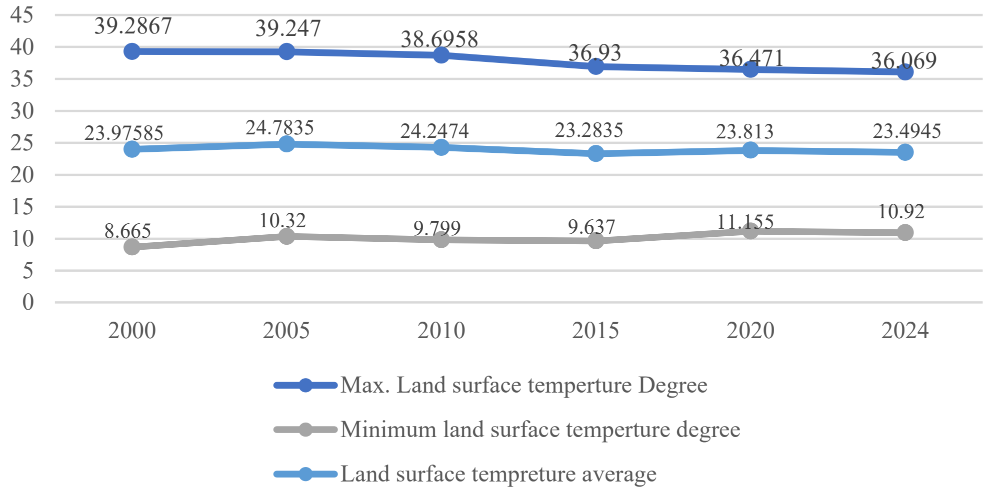


**Figure 8.** The annual maximum, minimum, and average LST in January in 2000, 2005, 2010, 2015, 2020, and 2024, Google Earth data source.

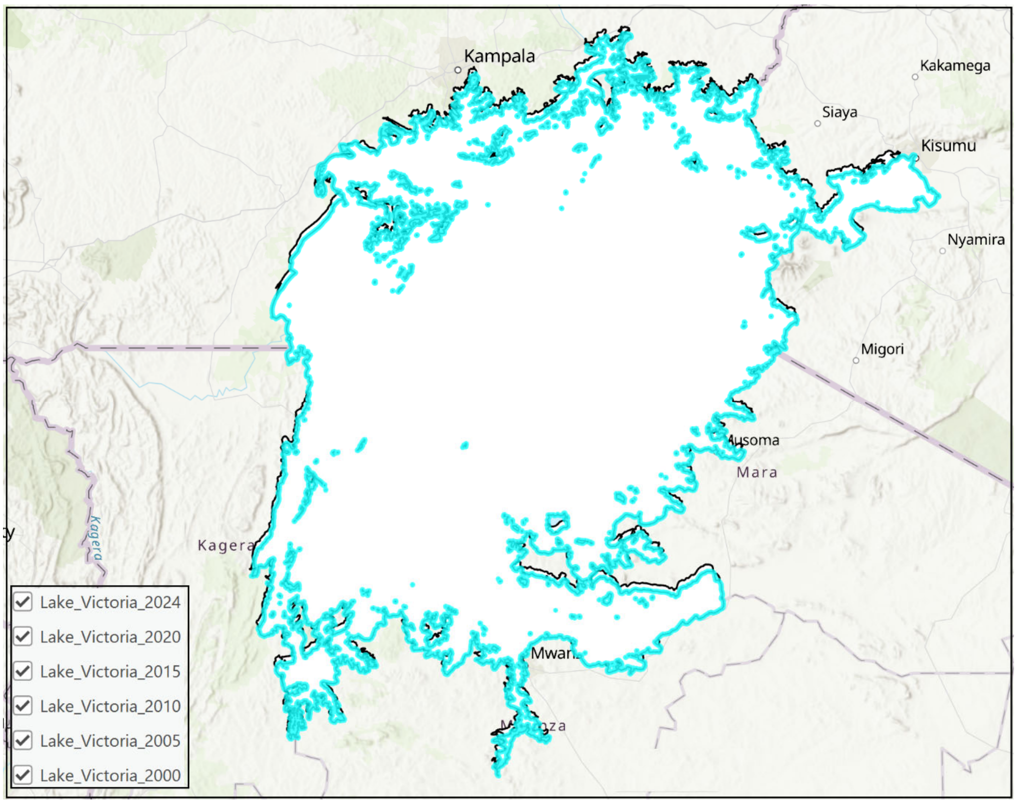


**Figure 9.** The polygon layers that represent the lake's boundaries in 2000–2023.

The lake's water area variation in the period 2000–2023 is shown in Figure 10 below. The water surface area, averaging 61,559 km, has been increasing since 2000 with an average rate of 1.3%. Gathering historical data is of the utmost importance when it comes to comprehending and analyzing climate change. The water levels in Lake Victoria can provide valuable insights into the changes that have been influenced by various climatic indicators, such as El Niño and Southern Oscillation (ENSO), Indian Ocean Dipole, and other large-scale climate systems [61]. For instance, the rainfall that occurred during the El Niño of 1998 exemplifies the intricate interplay of climate cycles that impact the environment [39].

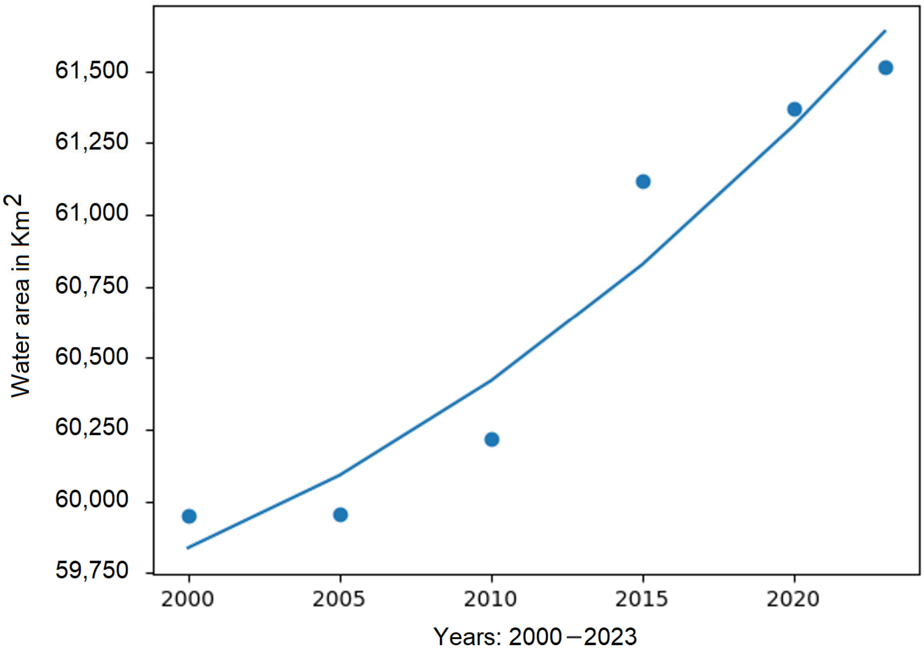


**Figure 10.** Lake Victoria's water area variation in the period 2000–2023.

The LVB's spatial area serves as a hub for water users. Understanding how land use systems impact the lake water is essential because it will impact the lake's social, economic, and environmental parameters [62]. To standardize methodology and interpretations, countries sharing transboundary resources need to collaborate. Land use policies and the economic environment that influence land cover changes differ by country [63]. The LVB documented changes, occurring over 8000 years, indicate noteworthy ecological changes caused by changes in LULC. Significant modifications include agricultural land expansions, intensification, and forest and woodland area drops [59]. The impact of those changes was significant for agriculture as the major economic land use in the basin area includes sugar, cotton, tea, and coffee. Furthermore, 75% of the LVB workforce are farmers [64]. Therefore, the LULC change increases deforestation and introduces new unsustainable farming methods, leading to soil erosion and poor nutrition [65].

It is important to note that climate change involves multiple factors. While perception may play a crucial role, there are other factors at play as well. Those factors may include tidal motions similar to those seen in the sea. These motions have a significant impact, causing the water level to be high on one side and low on the other side when the tide is high. Additionally, some of these tidal motions can occur in the outflows and impact the LV water level, such as in the case of the White Nile at Jinja. In 2000, dry conditions threatened Victoria Lake because of the temporary drying out of Simiyu River Basin wetlands as pastoralism impacted their carrying capacity through grazing during droughts [65].

The change in water level has a significant impact on communities in the basin area, particularly on energy generation. For example, after the expansion of the Nalubaale dam and a mid-2000s drought, water levels decreased, prompting communities to relocate closer to the shore. Second, since October 2019, around 200,000 people have been displaced or left homeless due to submerged homes. Subsequent steady increases since 2007, especially in 2020, have left many communities vulnerable to floods [56,61,62]. Third, various developments around Lake Victoria and the outflow river discharges were flooded and economically impacted. The Kenya Meteorological Department predicted an increase in the LV level since the fall of 2019, causing widespread destruction in various regions [66]. Fifth, the replacement of natural ecosystems with impervious surfaces reduces soil moisture absorption, while removing forest cover and wetlands worsens flooding. In addition to removing some of the forests, flooding causes significant changes in vegetation cover, replacing broad areas of savanna plants with rainforests [67]. Sixth, a forecast was made that the increase in water levels and flooding that occurred in 2020 and 2021 will benefit the lake and result in a quick recovery from drought events by June 2022 [68].

It is not deniable that the regional governments' efforts are being made to address the changes that are happening in the lake water. For example, the CIWA-funded Nile Cooperation for Climate Resilience (NCCR) is starting to manage the data and institutional gaps by improving the water quantity and quality in the Lake Victoria Basin (LVB) [62]. Moreover, the Kenyan government introduced a master plan to balance the capacity for investment planning in the lake basin, highlighting the drivers of declining water quality in the lake [60,64]. However, Kenya is making huge initiatives to mitigate this change, but serious action is required from the Ugandan government, as Uganda is the main contributor to the negative change in the water quality.

### *3.5. Articulation of Policy Changes Needed to Address These Complex Problems*

To tackle the complex issues affecting Lake Victoria, it is crucial to have a thorough policy framework that covers agricultural, socio-economic, political, and diplomatic factors. Agricultural policies need to encourage sustainable practices like agroecology and responsible fishing to address pollution and overfishing [69]. Socio-economic programs need to prioritize empowering communities with education and vocational training to help them broaden their sources of income and decrease reliance on lake resources [69]. Regarding politics, it is essential to create a transboundary governance body with representatives from Uganda, Kenya, and Tanzania for organized resource management and conflict resolution [70]. Moreover, bolstering diplomatic efforts via regional cooperation agreements can encourage cooperation and build trust among countries that border a lake, encouraging a joint commitment to its well-being [71]. The implementation of these coordinated policy adjustments is essential for promoting sustainable development and enhancing the ability of communities relying on Lake Victoria to withstand challenges.

## 4. Limitation and Future Research

Although the impact of Lake Victoria is crucial to millions of African countries' inhabitants, research in the following areas is limited. Firstly, several pieces of literature focus on the specific changes in LULC in the LVB over various years. Many of these papers highlight the Kenyan and Ugandan parts of the basin. However, only the Siamu River Basin has been studied in the Tanzanian part of the LVB [70,72]. Future research should also include the Rwandan and Burundian parts of the LVB. Secondly, before the 2020 floods, projections for the VL basin indicated an increase in temperature levels and a decrease in precipitation [73,74]. Following the floods, it is assumed that urban areas and croplands within the basin dramatically reduced, indicating a complete absence of the LULC analysis after the increase in the LV water level. Thirdly, the LULC has a significant impact on the water quality of the Lake Victoria Basin (LVB) [38,75]. However, this topic has limited research, particularly in the Tanzanian portion of the lake. Typically, water quality analysis research is focused on only one country's part of the basin, and each research study uses a different methodology. These methodological variations can affect the results of the analysis and make it challenging to compare the water quality among the different countries, thus hindering a complete understanding of the lake's overall water quality [76]. Fourthly, it is crucial to conduct further climate research and consider non-meteorological factors that contribute to flooding. Fifthly, although remote sensing data is available, the relationships between land cover classes have yet to be demonstrated. Moreover, limited research highlights possible correlations between environmental procedures and natural resources used in this shared basin between five countries.

It has been observed that some literature forecasts the environmental situation in LV, but the data used does not consider recent water events. It is crucial to have updated forecasts after 2020 to guide planning strategies and policies toward managing the changes in land use and waste management, especially for plastic [77]. The updated forecast will help prevent biodiversity loss [78] and protect the inhabitants of the LVB from unpredictable future disasters.

## 5. Conclusions

To conclude, this research used multi-source remote sensing data to examine the impact of LULC and climate change, represented by LST, on Lake Victoria. LULC and LST datasets were obtained from MODIS data, while NDWI layers were derived from Landsat 7 ETM+ and Sentinel-2 data. Analysis showed that climate change (represented by LST) and human activities (represented by LULC) contributed to the hydrological changes in the lake, leading to displacement, economic impacts, and infrastructure threats. Anthropogenic activities have had a significant impact on the environmental balance of the Lake Victoria Basin. LULC changes resulting from deforestation, urbanization, and other land uses are the primary cause of the decline in water quality, which affects the ecosystem and the quantity of water in the lake. This study highlighted the complex relationship between LULC changes and climate by examining the dynamics of land surface temperature. It underscores the need to identify solid trends in LULC and environmental changes in the Lake Victoria Basin from 2020 to the present. Analysis of the lake's water areas shows an increasing trend during the study area. Finally, the findings emphasize the importance of forecasting these changes to develop sustainable strategies for land management and policies to mitigate their effects in the future [79,80].

**Author Contributions:** Conceptualization, M.A. and T.A.; methodology, M.A. and T.A.; software, A.E.; validation, M.A., L.D. and R.G.; formal analysis, M.A. and T.A.; investigation, T.A. and R.G.; data curation, L.D. and A.E.; writing—original draft preparation, T.A., R.G. and M.A.; writing—review and editing, L.D. and A.E.; visualization, L.D. and R.G. All authors have read and agreed to the published version of the manuscript.

**Funding:** The work in this paper was supported, in part, by the Open Access Program from the American University of Sharjah. This paper represents the opinions of the author(s) and does not mean to represent the position or opinions of the American University of Sharjah.

**Data Availability Statement:** The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

**Conflicts of Interest:** Authors declare no conflict of interest.

## References


1. In 100,000 Years Lake Victoria Has Dried Up Three Times—It Could Happen Again. Available online: https://qz.com/africa/1791330/lake-victoria-could-dry-up-again-like-it-did-100000-years-ago (accessed on 16 October 2023).
2. Okungu, J.O.; Rutagemwa, D.K.; Ssenfuma-Nsubuga, M.; Abuodha, J.O.Z.; Mwanuzi, F.L.; Muyodi, F.J.; Hecky, R.E. *Lake Victoria Environment Management Project (LVEMP) Water Quality and Ecosystem Status: Lake Victoria Regional Water Quality Synthesis Report*; SCIRP Open Access: Nairobi, Kenya, 2005.
3. Liu, Y.; Wu, G.; Fan, X.; Gan, G.; Wang, W.; Liu, Y. Hydrological impacts of land use/cover changes in the Lake Victoria basin. *Ecol. Indic.* **2022**, *145*, 109580. [CrossRef]
4. Awange, L.; Saleem, A.; Sukhadiya, M.; Ouma, O.; Kexiang, H. Physical dynamics of Lake Victoria over the past 34 years (1984–2018), Is the lake dying? *Sci. Total Environ.* **2019**, *658*, 199–218. [CrossRef]
5. Awange, L. *Lake Victoria Monitored from Space*; Springer International Publishing: Cham, Switzerland, 2021. Available online: https://link.springer.com/content/pdf/10.1007/978-3-030-60551-3.pdf (accessed on 21 March 2024).
6. Odada, E.; Ochola, W.; Olago, D. Drivers of ecosystem change and their impacts on human well-being in Lake Victoria basin. *Afr. J. Ecol.* **2009**, *47*, 46–54. [CrossRef]
7. Ochola, O. Land Cover, Land Use Change and Related Issues in the Lake Victoria Basin: States, Drivers, Future Trends and Impacts on Environment and Human Livelihoods, United Nations Environment Programme (UNEP); Pan African START Secretariat (PASS), Nairobi, Kenya. 2009. Available online: http://hdl.handle.net/1834/7371 (accessed on 21 March 2024).
8. Twesigye, C.; Onywere, S.; Getenga, Z.; Mwakalila, S.; Nakiranda, J. The Impact of Land Use Activities on Vegetation Cover and Water Quality in the Lake Victoria Watershed. *Open Environ. Eng. J.* **2011**, *4*, 66–77. Available online: https://benthamopen.com/contents/pdf/toenviej/toenviej-4-66.pdf (accessed on 13 January 2024). [CrossRef]
9. Kayombo, S.; Jorgensen, S.E. Lake Victoria. *Exp. Lessons Learn. Brief.* 2006, pp. 431–446. Available online: https://www.ilec.or.jp/wp-content/uploads/pub/27_Lake_Victoria_27February2006.pdf (accessed on 24 November 2023).
10. James, R.; Amasi, A.; Wynants, M.; Njau, K. Assessing the Impacts of Land Use and Climate Changes on River Discharge towards Lake Victoria. *Earth* **2023**, *4*, 365–383. Available online: https://www.researchgate.net/publication/370647256_Assessing_the_Impacts_of_Land_Use_and_Climate_Changes_on_River_Discharge_towards_Lake_Victoria (accessed on 10 November 2023). [CrossRef]

11. Chiyuan, B.; Jinren, A.; Alistair, L.; Borthwick, C.; Lin, D. A preliminary estimate of human and natural contributions to the changes in water discharge and sediment load in the Yellow River. *Glob. Planet. Change* **2011**, *76*, 196–205. [CrossRef]
12. Blake, W.; Kelly, C.; Wynants, M.; Patrick, A.; Lewin, S.; Lawson, J.; Nasolwa, E.; Page, A.; Nasseri, M.; Marks, C.; et al. Integrating land-water-people connectivity concepts across disciplines for co-design of soil erosion solutions. *Land Degareation Development* **2020**, *32*, 3415–3430. [CrossRef]
13. Parveen, S.; Basheer, J.; Praveen, B. A Literature Review on Land Use Land Cover Changes. *Int. J. Adv. Res.* **2018**, *6*, 1–6. [CrossRef]
14. East African Consortium for Clinical Research. Available online: https://eaccr.tghn.org/ (accessed on 19 February 2024).
15. Lake Victoria's Rise due to Many Factors, Including Climate Change. Available online: https://africa.cgtn.com/lake-victorias-rise-due-to-many-factors-including-climate-change/ (accessed on 15 January 2024).
16. Pietroiusti, R.; Vanderkelen, I.; Otto, F.; Barnes, C.; Temple, L.; Akurut, M.; Bally, P.; Lipzig, N.; Thiery, W. Possible role of anthropogenic climate change in the record-breaking 2020 Lake Victoria levels and floods. *EGUsphere* **2023**, *15*, 225–264. [CrossRef]
17. Wakwabi., O.; Balirwa., J.; Ntiba, J. *Aquatic Biodiversity of Lake Victoria Basin, United Nations Environment Programme (UNEP)*; Pan African START Secretariat (PASS): Uganda, Kenya, 2019. Available online: http://hdl.handle.net/1834/7360 (accessed on 10 November 2023).
18. Yang, L.; Driscol, J.; Sarigai, S.; Wu, Q.; Chen, H.; Lippitt, C.D. Google Earth Engine and artificial intelligence (AI): A comprehensive review. *Remote Sens.* **2022**, *14*, 3253. [CrossRef]
19. Tamiminia, H. Google Earth Engine for geo-big data applications: A meta-analysis and systematic review. *ISPRS J. Photogramm. Remote Sens.* **2020**, *164*, 152–170. [CrossRef]
20. Gorelick, N.; Hancher, M.; Dixon, M.; Ilyushchenko, S.; Thau, D.; Moore, R. Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sens. Environ.* **2017**, *202*, 18–27. [CrossRef]
21. Gao, B.C. NDWI—A normalized difference water index for remote sensing of vegetation liquid water from space. *Remote Sens. Environ.* **1996**, *58*, 257–266. [CrossRef]
22. Mugo, R.; Waswa, R.; Nyaga, J.W.; Ndubi, A.; Adams, E.C.; Flores-Anderson, A.I. Quantifying Land Use Land Cover Changes in the Lake Victoria Basin Using Satellite Remote Sensing: The Trends and Drivers between 1985 and 2014. *Remote Sens.* **2020**, *12*, 2829. [CrossRef]
23. Ali, T.; Mortula, M.; Mohsen, B.; Mohsen, L.; Dronjak, R.; Gawai, S.; Atabay, Z.; Khan, K. Evaluation of microplastic pollution along the Dubai coast using sampling and remote sensing techniques: An empirical modelling using Sentinel-2 imagery. *J. Sustain. Dev. Energy Water Environ. Syst.* **2023**, *12*, 1110482. Available online: https://www.sdewes.org/jsdewes/pid11.0482 (accessed on 13 January 2024).
24. Mugo, R.M.; Limaye, A.S.; Nyaga, J.W.; Farah, H.; Wahome, A.; Flores, A. Linking Land Use Changes to Surface Water Quality Variability in Lake Victoria: Some Insights from Remote Sensing, AGU Fall Meeting Abstracts. 2016. Available online: https://ui.adsabs.harvard.edu/abs/2016AGUFMGC41B1101M/abstract (accessed on 13 January 2024).
25. Nyamweya, C.; Lawrence, T.; Ajode, M.; Smith, S.; Achieng, A.; Barasa, J.; Masese, F.; Taabu-Munyaho, F.; Mahongo, S.; Kayanda, R.; et al. Lake Victoria: Overview of research needs and the way forward. *J. Great Lakes Res.* **2023**, *49*, 102211. [CrossRef]
26. Kundu, P.M.; Olang, L.O. The Impact of Land Use Change on Runoff and Peak Flood Discharges for the Nyando River in Lake Victoria Drainage Basin, Kenya, Environmental Science, Geography. 2011. Available online: https://www.semanticscholar.org/paper/The-impact-of-land-use-change-on-runoff-and-peak-in-Kundu-Olang/8b9cdd4e25e3a1678165362394559260e093b931 (accessed on 13 January 2024).
27. Kiggundu, N.; Anaba, L.; Banadda, N.; Wanyama, J.; Kabenge, I. Assessing Land Use and Land Cover Changes in the Murchison Bay Catchment of Lake Victoria Basin in Uganda. *J. Sustain. Dev.* **2018**, *11*, 44. [CrossRef]
28. Maitima, J.; Olson, J.; Mugatha, S.; Mutie, I. Land use changes, impacts and options for sustaining productivity and livelihoods in the basin of Lake Victoria. *J. Sustain. Dev. Afr.* **2010**, *12*, 189–206. Available online: https://www.researchgate.net/publication/257657203_Land_use_changes_impacts_and_options_for_sustaining_productivity_and_livelihoods_in_the_basin_of_lake_Victoria (accessed on 13 January 2024).
29. Mngube, F.; Kapiyo, R.; Aboum, R.; Anyona, D.; Dida, G. Subtle Impacts of Temperature and Rainfall Patterns on Land Cover Change Overtime and Future Projections in the Mara River Basin, Kenya. *Open J. Soil Sci.* **2020**, *10*, 327–358. [CrossRef]
30. Consideration of the Baseline Report on Plastic Waste and the Stocktaking of Initiatives on Plastic Waste, UNEP UNITED NATIONS. 2020. Available online: https://gridarendal-website-live.s3.amazonaws.com/production/documents/:s_document/554/original/UNEP-CHW-PWPWG.1-INF-4.English.pdf?1594295332 (accessed on 10 November 2023).
31. Egessa, R.; Nankabirwa, A.; Ocaya, H.; Pabire, W. Microplastic pollution in surface water of Lake Victoria. *Sci. Total Environ.* **2020**, *741*, 140201. [CrossRef] [PubMed]
32. Land Resources and Agriculture, Chapter 5, Land Resources and Agriculture. 2015. Available online: https://ncert.nic.in/ncerts/l/legy205.pdf (accessed on 10 November 2023).
33. Habitat Destruction (Agricultural Resource Economics), The Encyclopedia of the Earth. 2016. Available online: https://editors.eol.org/eoearth/wiki/Habitat_destruction_(Agricultural_&_Resource_Economics) (accessed on 16 October 2023).
34. Lake Victoria, African Great Lakes. Available online: Https://Www.Africangreatlakesinform.Org/Article/Lake-Victoria (accessed on 16 October 2023).

35. Nyamweya, C.; Natugonza, V.; Munyaho, A.; Aura, C.; Njiru, J.; Ongore, C.; Mangeni, R.; Kashindye, B.; Odoli, C.; Ogari, Z.; et al. A century of drastic change: Human-induced changes of Lake Victoria fisheries and ecology. *Fish. Res.* **2020**, *230*, 105564. [CrossRef]
36. Forkuor, G.; Conrad, C.; Thiel, M.; Landmann, T.; Barry, B. Evaluating the sequential masking classification approach for improving crop discrimination in the Sudanian Savanna of West Africa. *Comput. Electron. Agric.* **2015**, *118*, 380–389. [CrossRef]
37. Intergovernmental Panel on Climate Change (IPCC). *Climate Change 2021—The Physical Science Basis; Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK, 2023.
38. Climate Change 2021: The Physical Science Basis. Available online: https://scholar.google.com/scholar_lookup?title=Climate+Change+2021%E2%80%94The+Physical+Science+Basis&author=Intergovernmental+Panel+on+Climate+Change+(IPCC)&publication_year=2023 (accessed on 24 November 2023).
39. Shinhu, R.; Amasi, R.; Wynants, M.; Nobert, J.; Mtei, K.; Njau, K. Assessing the Impacts of Land Use and Climate Changes on River Discharge towards Lake Victoria. *Earth* **2023**, *4*, 365–383. Available online: https://www.mdpi.com/2673-4834/4/2/20 (accessed on 24 November 2023). [CrossRef]
40. Relief as Lake Victoria Water Levels Recede after Destructive Record High. 2021. Available online: https://www.theeastafrican.co.ke/tea/news/east-africa/relief-as-lake-victoria-water-levels-recede-3507314 (accessed on 21 November 2023).
41. The Implication of Floods to Food Security During and the Aftermath of Covid–19 Pandemic in Uganda, Covid-19 Issue 03, June/2020. Available online: Https://Acsa-Ug.Org/Wordpress/Wp-Content/Uploads/2020/06/The-Implication-Of-Floods-To-Food-Security-During-And-The-Aftermath-Of-Covid19-Pandemic-In-Uganda.Pdf (accessed on 24 November 2023).
42. Kajuni, R.; Kijazi, A.; Mtani, B.; Monjare, J. Land cover changes between 2010 and 2020 in Lake Victoria basin in Tanzania. In *Ecohydrology from Catchment to Coast, The Nile River System, Africa*; Elsevier: Amsterdam, The Netherlands, 2024; pp. 133–146. [CrossRef]
43. Onyango, D.; Ikporukpo, C.; Taiwo, J.; Opiyo, S.; Otieno, K. Comparative Analysis of Land Use/Land Cover Change and Watershed Urbanization in the Lakeside Counties of the Kenyan Lake Victoria Basin Using Remote Sensing and GIS Techniques, Advances in Science. *Technol. Eng. Syst. J.* **2021**, *6*, 671–688. Available online: https://www.astesj.com/publications/ASTESJ_060278.pdf (accessed on 24 November 2023).
44. Barrett, K.; Okali, C. Community P Articip A Tion in the Management of Tsetse a Comparative Assessment of Impact and Sustainability, Report Submitted to the Animal Health Programme of the Department for International Development (Dfm). 1998. Available online: https://assets.publishing.service.gov.uk/media/57a08d9ae5274a31e0001964/R6553b.pdf (accessed on 24 November 2023).
45. Awange, J.; Aluoch, J.; Ogallo, L.; Omulo, M.; Omondi, P. Frequency and severity of drought in the Lake Victoria region (Kenya) and its effects on food security. *Clim. Res.* **2007**, *33*, 135–142. Available online: https://www.jstor.org/stable/24869328 (accessed on 24 November 2023). [CrossRef]
46. Nyandega, I. Assessment and Characterization of Drought Occurrence in the Lake Victoria Basin of Kenya: Case Study of West Kenya. Ph.D. Thesis, University of Nairobi, Nairobi, Kenya, 1990. Available online: https://scholar.google.com/citations?view_op=view_citation&hl=en&user=F3IHPGIAAAAJ&citation_for_view=F3IHPGIAAAAJ:UebtZRa9Y70C (accessed on 24 November 2023).
47. Casanova, M.; Casanova, A. Current and Future Risks of Cropping Wetlands in Victoria, the State of Victoria Department of Environment, Land, Water and Planning, Technical Report, 2016. [CrossRef]
48. Obiero, K.; Raburu, P.; Okeyo-Owuor, J.; Raburu, E. Community perceptions on the impact of the recession of Lake Victoria waters on Nyando Wetlands. *Sci. Res. Essays* **2012**, *7*, 1647–1661. Available online: https://www.researchgate.net/publication/265885698_Community_perceptions_on_the_impact_of_the_recession_of_Lake_Victoria_waters_on_Nyando_Wetlands (accessed on 24 November 2023).
49. Olang, L.; Fürst, J. Effects of land cover change on flood peak discharges and runoff volumes: Model estimates for the Nyando River Basin, Kenya. *Hydrol. Process.* **2011**, *25*, 80–89. Available online: https://www.researchgate.net/publication/229858961_Effects_of_Land_Cover_Change_on_Flood_Peak_Discharges_and_Runoff_Volumes_Model_Estimates_for_the_Nyando_River_Basin_Kenya (accessed on 5 February 2024). [CrossRef]
50. Bradley, J.; Imboma, T.; Bradley, D. Birds of Mount Kisingiri, Nyanza Province, including a preliminary survey of the Gwassi Hills Forest Reserve and a species new to Kenya. *J. East Afr. Ornithol.* **2015**, *35*, 11–38. Available online: https://www.researchgate.net/publication/305433629_Birds_of_Mount_Kisingiri_Nyanza_Province_including_a_preliminary_survey_of_the_Gwassi_Hills_Forest_Reserve_and_a_species_new_to_Kenya (accessed on 5 February 2024).
51. A Lake on Its Deathbed; Who Can Save Lake Victoria ? *Geodata Journalism. Mapping Stories on Water Issues in the Nile Basin, Uganda*. 2023. Available online: https://infonile.org/en/2023/12/a-lake-on-its-deathbed/#:~:text=It%20provides%20water%20for%20drinking,both%20human%20and%20aquatic%20life (accessed on 20 January 2024).
52. Albright, T.; Moorhouse, T.; Mcnabb, T. The Rise and Fall of Water Hyacinth in Lake Victoria and the Kagera River Basin, 1989–2000. *J. Aquat. Plant Manag.* **2004**, *42*, 73–84. Available online: https://www.researchgate.net/publication/228903410_The_rise_and_fall_of_water_hyacinth_in_Lake_Victoria_and_the_Kagera_River_Basin_1989-2001 (accessed on 5 February 2024).
53. Herschy, R. *Victoria Lake, Encyclopedia of Earth Sciences Series Book Series (EESS)*; Springer: Dordrecht, The Netherlands, 2012. Available online: https://link.springer.com/referenceworkentry/10.1007/978-1-4020-4410-6_176#citeas (accessed on 5 February 2024).
54. Khaki, M.; Awange, J. The 2019–2020 Rise in Lake Victoria Monitored from Space: Exploiting the State-of-the-Art GRACE-FO and the Newly Released ERA-5 Reanalysis Products. *Sensors* **2021**, *21*, 4304. [CrossRef] [PubMed]

55. Lake Victoria's Rising Waters, Nasa Earth Observatory. 2021. Available online: https://earthobservatory.nasa.gov/images/148414/lake-victorias-rising-waters (accessed on 29 January 2024).
56. Wasigea, J.; Groena, T.; Smalinga, E.; Jettena, V. Monitoring basin-scale land cover changes in Kagera Basin of Lake Victoria using ancillary data and remote sensing. *Int. J. Appl. Earth Obs. Geoinf.* **2013**, *21*, 32–41. Available online: https://www.sciencedirect.com/science/article/abs/pii/S0303243412001687 (accessed on 5 February 2024). [CrossRef]
57. Musamba, E.; Ngaga, Y.; Boon, E.; Giliba, R. Impact of Socio-economic Activities around Lake Victoria: Land Use and Land Use Changes in Musoma Municipality, Tanzania. *J. Hum. Ecol.* **2011**, *35*, 143–154. [CrossRef]
58. Awange, L.; Sharifi, A.; Ogonda, G. The Falling Lake Victoria Water Level: GRACE, TRIMM and CHAMP Satellite Analysis of the Lake Basin. *Water Resour. Manag.* **2008**, *22*, 775–796. [CrossRef]
59. Lake Victoria Basin Atlas of Our Changing Environment, Lake Victoria Basin Commission East African Community. 2017. Available online: https://gridarendal-website-live.s3.amazonaws.com/production/documents/:s_document/318/original/LakeVicAtlas_screen.pdf (accessed on 5 February 2024).
60. Wange, J.; Ogalo, L.; Bae, K.; Were, P.; Omondi, P.; Omute, P.; Omullo, M. Falling Lake Victoria water levels: Is climate a contributing factor? *Climatic Change*. Available online: https://www.icpac.net/media/documents/Falling-Lake-Victoria-water-levels_1.pdf (accessed on 5 February 2024).
61. Tong, X.; Pan, H.; Xie, H.; Xu, H.; Li, F.; Chen, L.; Luo, X.; Liu, S.; Chen, P.; Jin, Y. Estimating water volume variations in Lake Victoria over the past 22 years using multi-mission altimetry and remotely sensed images. *Remote Sens. Environ.* **2016**, *187*, 400–413. [CrossRef]
62. Onyango, D.; Ikporukpo, C.; Taiwo, J.; Opiyo, S. Land Use and Land Cover Change as an Indicator of Watershed Urban Development in the Kenyan Lake Victoria Basin. *Int. J. Sustain. Dev. Plan.* **2021**, *16*, 335–345. [CrossRef]
63. Floods Leave Trail of Destruction and Devastation in Lake Region, Nation. 2023. Available online: https://nation.africa/kenya/health/floods-leave-trail-of-destruction-and-devastation-in-lake-region-4265952#google_vignette (accessed on 6 January 2024).
64. Sharma, R.; Rimal, B.; Baral, H.; Nehren, U.; Paudyal, K.; Sharma, S.; Rijal, S.; Ranpal, S.; Acharya, R.P.; Alenazy, A.A.; et al. Impact of Land Cover Change on Ecosystem Services in a Tropical Forested Landscape. *Resources* **2019**, *8*, 18. [CrossRef]
65. Chumo, K. Coping with Drought among the Communities Living in the Lake Victoria Basin of Kenya. *J. Soc. Dev. Sci.* **2012**, *3*, 342–349. [CrossRef]
66. Mugo, N.; Karanja, N.; Gachene, K. Assessment of soil fertility and potato crop nutrient status in central and eastern highlands of Kenya. *Sci. Rep.* **2020**, *10*, 7779. [CrossRef] [PubMed]
67. Nicholson, S.; Yin, X. Rainfall Conditions in Equatorial East Africa during the Nineteenth Century as Inferred from the Record of Lake Victoria. *Clim. Change* **2001**, *48*, 387–398. [CrossRef]
68. Kihanya, M.; Why the Water Level of L. Victoria Is Not the Same at Different Places, Figures Consultancy. *The Sunday Nation, Nairobi*, 10 May 2020. Available online: https://www.figures.co.ke/Articles/2020/10-May-20_Lake_Victoria_Levels.html (accessed on 5 February 2024).
69. Dida, M.O.; Abila, R. Sustainable fisheries management in Lake Victoria: Policies and challenges. *J. Environ. Manag.* **2020**, *264*, 110482.
70. Varughese, M.; Kc, S. Protecting Lake Victoria for a Green, Resilient, and Inclusive Future, The Water Blog. 2022. Available online: https://blogs.worldbank.org/water/protecting-lake-victoria-green-resilient-and-inclusive-future (accessed on 15 December 2023).
71. Temoltzin-Loranca, Y.; Gobet, E.; Vannière, B.; Leeuwen, J.; Wienhues, G.; Courtney-Mustaphi, C.; Kishe, M.; Muschick, M.; King, L.; Misra, P.; et al. Long-term ecological successions of vegetation around Lake Victoria (East Africa) in response to latest Pleistocene and Early Holocene climatic changes, Palaeogeography, Palaeoclimatology. *Palaeoecology* **2023**, *631*, 111839. [CrossRef]
72. Pavur, G.; Lakshmi, V. Observing the recent floods and drought in the Lake Victoria Basin using Earth observations and hydrological anomalies. *J. Hydrol. Reg. Stud.* **2023**, *46*, 101347. [CrossRef]
73. Walingo, M.; Liwenga, E.; Kangalawe, R.; Madulu, N.; Kabumbuli, R. Perceived impact of land use changes and livelihood diversification strategies of communities in the LakeVictoria Basin of Kenya. *J. Agric. Biotechnol. Sustain. Dev.* **2009**, *1*, 69–78. Available online: https://www.researchgate.net/publication/242099240_Perceived_impact_of_land_use_changes_and_livelihood_diversification_strategies_of_communities_in_the_Lake_Victoria_Basin_of_Kenya#fullTextFileContent (accessed on 5 February 2024).
74. Floods Blamed on Uganda's Policy on Releasing Lake Victoria Water, the Citizen. 2020. Available online: https://www.thecitizen.co.tz/tanzania/news/national/floods-blamed-on-uganda-s-policy-on-releasing-lake-victoria-water--2709672 (accessed on 23 November 2023).
75. The Study of Integrated Regional Development Master Plan for the Lake Basin Development Area 1 Lake Basin Development, Kenya. 1997. Available online: https://openjicareport.jica.go.jp/pdf/10407005.pdf (accessed on 5 February 2024).
76. Walle, J.; Thiery, W.; Brogli, R.; Martius, O.; Zscheischler, J.; Lipzig, N. Future intensification of precipitation and wind gust associated thunderstorms over Lake Victoria. *Weather Clim. Extrem.* **2021**, *34*, 100391. [CrossRef]
77. Rousso, B.; Bertone, E.; Stewart, R.; Hamilton, D. A systematic literature review of forecasting and predictive models for cyanobacteria blooms in freshwater lakes. *Water Res.* **2020**, *182*, 115959. [CrossRef] [PubMed]
78. Mjema, J. The socio-economic impacts of pollution in Lake Victoria: A regional perspective. *Afr. J. Aquat. Sci.* **2019**, *44*, 1–12.

79. Ogutu-Ohwayo, R. The political dynamics of resource management in the Lake Victoria basin. *Int. J. River Basin Manag.* **2018**, *16*, 345–357.
80. East African Community. The Lake Victoria Basin: A regional integration approach. In *EAC Regional Development Strategy*; East African Community: Arusha, Tanzania, 2021.