A Systematic Review of Threats to the Sustainable Utilization of Transboundary Fresh Water Lakes: A Case Study of Lake Victoria.

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Abstract- For the countries within the Lake Victoria basin, sustainably managing it is critical to the harmonious survival of a vast array of biodiversity. The abundance of resources in and around the lake provides various vital ecosystem services (like food, transport, nutrient cycling, tourism, climate regulation as well as disease and flood control) for humans and countless other species. However, decades of unsustainable development practices combined with unchecked population growth are diminishing the lakes' productivity and threatening its very existence. Eutrophication, proliferation of alien species, water pollution, inappropriate fishing techniques, and climate change are among some of the anthropogenic and natural threats that are besieging Lake Victoria. In light of recent exploration and exploitation of minerals, oil, and gas further degradation of the watershed is not only eminent but a surety. However, to date the institutions mandated with the regional management of the basin have fallen short of their expectations and literature pertaining to the basin's management is quite outdated. There is urgent need to draw attention to the cause-effect relationship between the driving forces – pressures – state – impacts – responses, that diminish sustainable utilization and development of Lake Victoria. Using this indicator-based approach clearly highlights the nexus between the environmental metrics and anthropogenic interactions making decisions for practice and policy-making more sustainable. Overall, the need for robust integrated water management policies within the riparian countries is critical to simultaneously address conservation and development which are paramount in ensuring sustainable development and enhancing the lake's productivity. Sensitization and capacity building within the communities utilizing the lake as a primary source of income will mitigate detrimental impacts from unsustainable usage. More so, appropriate incentives and fines to deter pollution and illegal reclamation of wetlands and forests will promote regeneration of the ecosystem and recovery in the long term.

Index Terms- Lake Victoria, Threats, Sustainable Development, Transboundary, Fresh Water.

I. Introduction

Sustainable utilization of transboundary fresh water lakes the world over is under immense threat. With the anticipated sharp rise in demand for fresh water due to population growth and climate change, reliance on shared water resources is significantly increasing, and so is the eventual degradation of these finite resources[1]. This is particularly heightened in developing countries and regions like Africa were fresh water is quintessential to economic development, and sustainable livelihoods. For the past half of the century or more the drivers and challenges to transboundary fresh water management in Africa have been under more scrutiny in the region and on the international scene.[1]. In Africa earmarked policies and national efforts to protect water resources are often undermined by their transboundary nature which requires integrated, co-operative mechanisms for effective management of existing and emerging threats[2]. Transboundary fresh water resources are continuously threatened by over exploitation, and continued degradation from anthropogenic and natural process[3]. . In this regard Lake Victoria is no different. With a surface area of approximately 68,800 km2 and an average depth of 40m, it is Africa's largest lake[4]. In terms of volume however, it is the world's ninth largest continental lake containing approximately 2,424 cubic kilometers of water and the second largest fresh water lake by surface area after Lake Superior in North America[5]. The lake is at an altitude of 1135 m above sea level and lies on the between latitude 0.7°'N-3°'S and longitude 31.8°'E-34.8°'E[6, 7]. Annual rainfall in the lake area varies between 950 and 2450 mm and on the terrestrial part of the basin, it ranges from 450 to 950 mm. Because of its location at the equator it has all year round productivity[8]. Surrounded by Tanzania, Uganda and Kenya which control 51% (79570km^2), 43% (38913km^2), and 6% (28857km^2), of the catchment area respectively, the lake's 194,000 km^2 catchment area stretches further across Rwanda (20550km^2) and Burundi (13060km^2), please refer to Figure 1 which are within the upper watershed that drains into Lake Victoria through river Kagera[9, 10]. Given its size, it is not surprising that the lake plays vital ecological and socio-economical roles in the state of the entire East African region. It is used for hydroelectric energy production, fishery, tourism, freshwater supply, mining, waste disposal as well as transportation. Lake

Victoria is a habitat for numerous fish and bird species, including the crested crane and the sitatunga, a globally threatened species of water antelope [11, 12]. Wetlands occupy 40.8% of the basin, cropland 40.3%, while rest is grassland, savannah and shrub land. Wetlands within and around the basin provide important breeding grounds for fish,[13] and provide natural flood control and waste treatment services.

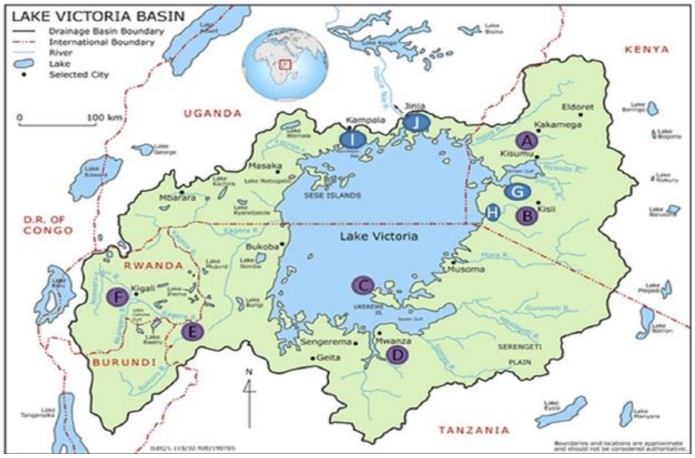

Figure 1: Countries boarding Lake Victoria, and the entire catchment area, including major towns found within the catchment area (A: Kisumu, B: Kisii, C: Ukerewe island D: Mwanza, E: Butare, F: Kigali, G: Homabay, H: Migori, I: Kampala and J: Jinja) Source: Munguti et *al* 2012

Lake Victoria is however under considerable pressure from a variety of interlinked human activities; and has undergone enormous ecosystem changes within the last 70 years. Environmental threats from activities like mining, overfishing, siltation from the erosion of deforested watersheds, proliferation of alien species, industrial pollution, eutrophication, urbanization and climate change are all contributing to a host of detrimental issues which have seriously threatened ecosystem function[14, 15]. Current water management policies are however, not robust enough to cope with the challenges, which has had significant impact on water use. Much of the literature on water resources in the East African countries is scattered and embedded in policy documents, strategic plans and reports produced by consultants and international organizations. Critical but otherwise basic data on population, health, and environment indicators that would adversely affect this ecosystem is inaccessible at basic community level making it difficult to assess, monitor, and communicate effectively about these connections[16]. Therefore, the search for more solutions in this domain remains an ongoing challenge[1]. With the rapidly growing population and improved living standards, the pressure on the lake's resources is increasing and per capita availability of water resources is reducing day by day[17]. This paper is a systematic review of various literature highlighting the continuous threats to Lake Victoria and its catchment area. The political, social and institutional gaps that have inhibited its sustainable utilization and ultimately compromised the entire ecosystem. It aims to inform and educate the public, drawing attention to the current environmental state of the basin, emphasizing key driving forces that may alter the state of environment and trends in ecosystem services that the basin provides. An explicit research strategy involving desktop literature retrieval of various studies from scientific databases namely; Web of Science, JSTOR, Science Direct, and Google Scholar were used. Grey literature including; UN Reports, and conference papers were also scrutinized to reduce publication bias. One hundred and thirty-six scientific articles from 1966 to 2019 were analyzed including 10% written within the last decade, then using inclusion and exclusion criteria based on relevance as level of threat; compilation was done.

II. Economic Significance and GDP of the Lake Victoria Basin (LVB)

The region's GDP and economic growth has historically been driven by agriculture due to its contribution to employment. In 2017 agriculture contributed to 41% of East Africa's real GDP growth[18]. Annual incomes in the region range from USD 90-270 per capita and gross economic product is at approximately USD3-4 billion per annum. Commercial fishing is among the highest grossing foreign exchange earner in the basin area, employing more than 2 million people in various capacities [19, 20] and supplying about one million metric tons of fish valued at about USD500 million annually. Nile Perch, Tilapia and Silver Cyprinid aka *daagaa or mukene* however, continue to be the most commercially viable fish species on the market with catches of 230,000 tonnes and 500,000 tonnes respectively per annum. Thirty two fish processing plants have in the last three decades been set up in the proximity of the lake for processing and eventual export supplying at least twenty six countries across the globe[21]. With the exception of Uganda and Tanzania the rest of the East African community members are importers of fisheries as well [22, 23]. Kenya's fishery export earnings increased from USD 0.4million in 1980 to USD66 million in 2003[24, 25]. Tanzania's fish exports leaped from USD8.3million in 1992 to USD112million in 2003 with Uganda registering USD82million in 1998 to 86million in 2003[25, 26]. Agriculture and Aquaculture aren't the only significant contributors to economic growth and development in the region. In addition to this, the lake also plays a vital role in regional transportation, with connections running between the major towns of Musoma, Mwanza, and Bukoba in Tanzania, Port Bell and Jinja in Uganda, and Kisumu in Kenya [27].The main source of commercial energy for electricity in East Africa is hydroelectricity which accounts for 78% of total production. Kenya is the biggest producer of hydropower in the East African Community, followed by Tanzania and Uganda [28]. Uganda is heavily reliant on hydroelectric power which is produced from three dams (Bujagali, Nalubaale and Kiira) on Lake Victoria. Together the dams produce 630MW of electricity which the country utilizes to run its budding industrial sector[29]. Currently, the major hydroelectric plants in Uganda at Owen Falls serve the double interest of regulating the outflow to Victoria Nile, and generating power, which supplies Kampala and Jinja as well as the export markets in Kenya and Bukoba in western Tanzania [28]. However, the revenues accrued from the abundance of natural resources pale in comparison to the short-term, income from the emerging mining sector. The basin contains significant metallic and none metallic mineral resources in various parts. The mines in Mwanza and Mare region in Tanzania are one example of the new economy that is emerging. Mwanza, in Tanzania with the largest share of its population below the poverty line in the country, is witnessing one of most rapid expansions of gold production in Africa. The Lake zone gold fields, south and east of Lake Victoria, up to the Kenya border, have yielded considerable exploration success with over 30 million ounces of gold "discovered" during the past twenty-three years, the largest deposits currently known outside Ghana and South Africa. However, copious land endowed with an array of natural resources hasn't translated to wealth for the inhabitants of the Lake Victoria basin. In Tanzania 41.3% of the inhabitants in the Lake Victoria basin live below the Basic Needs Poverty Line while 39% in Kenya and 34% in Uganda respectively.

III. THREATS HINDERING THE SUSTAINABLE UTILIZATION OF THE LAKE VICTORIA BASIN (LVB)

Lake Victoria's ecosystem and catchment area are under threat from multiple sources, each posing its own management challenge[11]. To better understand the casual effect of these threats classification of the following categories was done for this particular study; Socio-Economic threats, Ecological and Water Pollution. The lake has been facing these problems for the last sixty years. However, unprecedented acceleration of these threats in the last four decades has induced; degradation of the water quality owing mainly to eutrophication caused by inflow of nutrients flowing into the lake. Land degradation caused by unsustainable agricultural, soil erosion, tree/forest cutting etc. Growth of massive blooms of algae which are dominated by the potentially toxic blue-green variety. Water pollution caused by industrial and municipal discharges such as tanning paper, breweries, fish processing, Agro-processing etc. Introduction of the Nile Perch as an exotic fish species which has altered the food web structure and Water hyacinth infestation which covered about 2000 hectares in the Tanzania portion of the Lake by 1998 and 15,000 hectares in the whole lake the same year. While the threat is no longer a concern, for now (2020) the threat of a resurgence is ever present.

3.1. Socio-Economic Threats

3.1.1 Population

Lake Victoria catchment area is home to one of the highest rural population densities in the world, with over 100 residents per square kilometer in most places, and reaching densities as high as 1,200 residents per square kilometer in some areas[11, 30]. The catchment area is either directly/or indirectly intrinsic to sustaining the livelihoods of nearly 30 million people. In other words, nearly a third of the East African population are dependent on this region[5]. Agriculture, fisheries, and manufacturing are the main drivers of GDP in the catchment area. The basin's economy thrives mainly on agriculture with farmers primarily engaged in both commercial and subsistence farming including pastoralism. However, with the agricultural context heavily reliant on hydroclimatic conditions and sustainable land use management; poor agricultural practices, high poverty rates as well as the increasing demand for agricultural land have exacerbated or directly rendered the lake and its catchment area environmentally unstable. The rather remarkable growth in the agricultural and industrial sectors coupled with rapid population growth has however inevitably led to an increase in pollution and ultimately severe degradation of Lake Victoria. Figure 2 shows more than seven decades of continuous unchecked population growth within the lake proximity.

The lake acts as an important biodiversity conservation area as well as a climate moderator for some parts of the riparian countries. One of the largest inland water fishing sanctuaries, and a major inland water transport linkage for the three East Africa countries. The abundance of natural resources, expanding urbanization and opportunities for employment thereto have no doubt inevitably caused an influx of increased migration over the last couple of decades triggering population growth rates particularly close to the lakeshore in the catchment area[31], during the twentieth century this growth exceeded 3% per year within the riparian states. The average population density in the entire basin is about 165 persons/km2[32].Given the current population treads and projected estimations to 2050 (Table 1) the future livelihood of 40+ million people who depend on the lake for their survival will be seriously compromised if left unchecked.

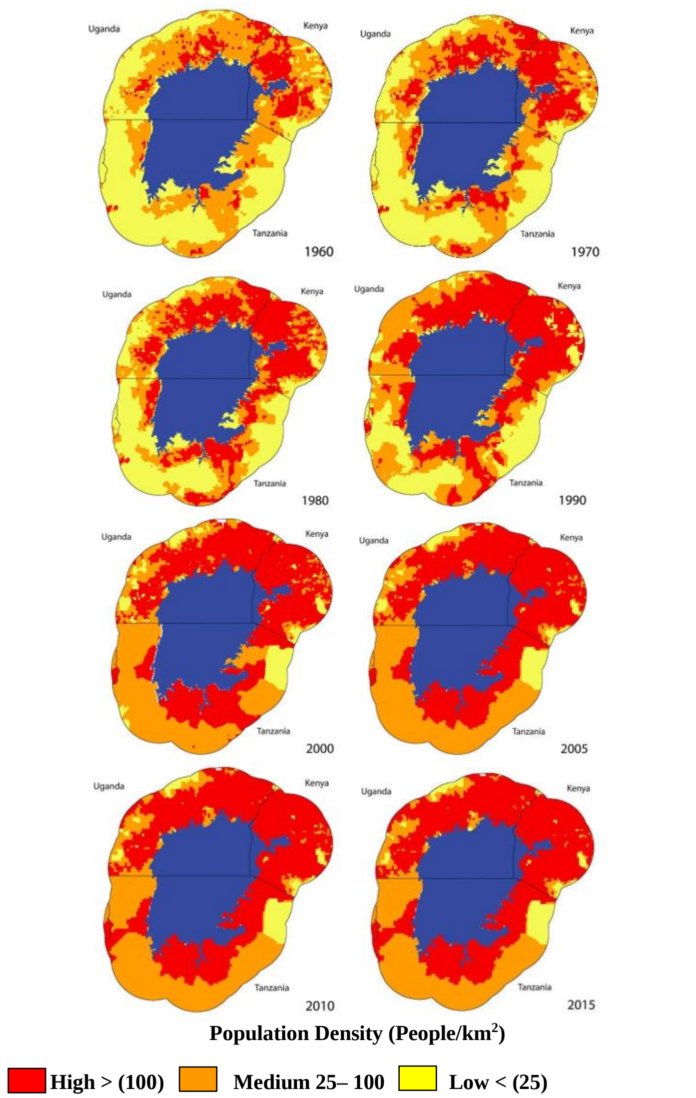

Figure 2: GIS imagery showing population growth round Lake Victoria basin in the last 7 decades.

The average population density on the Kenyan, Tanzanian and Ugandan sides of the basin is 297 persons/km², 97 persons/km2 and 635 persons/km2 respectively[33]. While migration may be partly responsible for population growth around the lake basin, a study conducted by Lopez- Carr et *al.* indicates that high fertility is an important factor in population growth as evidenced in the population dataset below[16]. Table 2 shows the total population of children under five in the region from 2000 to 2015 obtained from that particular study. The under 5 population increased from 6.43 million in 2000 to 8.27 million in 2010 and was projected to increase by approximately another million in 2015. Maps of percent growth of the under 5 population growth between 2010-2015 suggest that the Lake Victoria Basin is among a handful of most rapidly growing regions of under 5 growth on the continent[16].

Table 1: Total population and % increase relative to 2010

Lake Victoria Basin	2010	2020	2030	2050
Total Population (UN-Adjusted)	42,394,936	60,781,332	76,517,200	113,197,070
% increase relative to 2010		43.36%	80.48%	167%

Source : Lopez – Carr et *al* 2013

Table 2:Trend in the number of children in the LVB under 5 years of age

Lake Victoria Basin	**2000**	**2010**	**2015**
Population Under five	6,431,950	8,266,539	9,272774

Source : Lopez – Carr et *al* 2013

3.1.2 Unsustainable Land Use Techniques

The land degradation problems facing the Lake Victoria basin are multi-faceted. The factors are several and include both natural and human-induced driving forces. Protecting the land quality for the benefit of people is a major challenge in the basin. The basin has experienced dramatic changes in the past century as a result of unsustainable land use practices and techniques[34]. Unsustainable land use techniques currently utilized by the population have exerted pressure on previously existing vegetation causing, in extreme cases, a barren environment that yields unwanted sediment to downstream communities[35]. The need for fuelwood and timber as well as land for settlements and other uses in terrestrial environments has led to changes in the ecosystem accelerating the extinction of rare plant and animal species. The incremental loss of natural habitat in the Lake Victoria basin has reduced vegetation cover exposing soils to both wind and water erosion. Water erosion is extensive in many parts of the basin with approximately 45% of the land prone to water erosion[36]. Siltation of dams and the increased risk of flooding in rivers and estuaries are the direct effects of soil erosion and other degradation forces in the basin. The near annual flash floods in Budalangi and Kano plains have been linked to such forces emanating from point and non-point processes[37]. The driving forces for the pressures causing land degradation are as complex and diverse as the ecosystem and socioeconomic set up of the basin itself. These forces both natural and anthropogenic have led to the current state and trends either directly or indirectly. They include commercial lumbering activities for timber industries in the region, clearing for agriculture and other land use types such as urban expansion, infrastructure and grazing. Population expansion, forest and environmental policies, laws and economic forces are the direct pressures. The most degraded parts of the basin, both in terms of nutrient deficiencies and physical soil degradation, are areas currently used for open grazing and extraction of fuelwood. Areas currently used for subsistence agriculture are also characterized by both types of degradation but at lower prevalence rates than grazing areas[38]. In the Mara, Mwanza and Kagera regions, clearing of forests has resulted into deforestation, a dominant feature in most parts of the area where land is left bare following the expansion of settlements, livestock keeping, and agriculture[39]. Over the past three decades, intensified cultivation of marginal areas and clearance of natural habitats like wetlands, forests and mountainous areas has been witnessed in the Lake Victoria catchment area. These activities have been the main driving forces behind the escalating land degradation in the region. The forces are so intense that many wetlands such as Nakivubo Wetland in Uganda and Yala Swamp in Kenya are heavily degraded[40]. The main issues relating to forests and woodlands include deforestation and declining forest quality, incomplete inventory, monitoring, unsustainable governance with poor community involvement as well as unsustainable exploitation[41]. In 2000, land under forest in the three East African countries were estimated at 30.0-49.9% for Kenya and Tanzania and 15.0-29.9% for Uganda out of their total land area respectively. The deforestation rate was estimated at 0.5-0.9% for Kenya, more than 1.0% for Uganda and less than 0.1-0.4% for Tanzania [42]. Woodland areas that used to be over 20% of land area have almost disappeared. Exotic trees have replaced varieties of indigenous trees. Similarly, many of the original wildlife species that existed in the early 1930 to 1950s have undergone varying degrees of decline. Forests and woodlands in the lake basin support an estimated 150,000 plant and animal species with a myriad of invaluable economic value to human beings in terms of shelter, food, medicinal purposes and energy needs (both industrial and domestic). However, since their ecologic benefits accrue not only to the inhabitants of the basin, it is impractical to estimate their economic value. On-going indications are that unregulated wetland conversion may contribute to a decline of floral and faunal diversity through loss of habitat, destruction of *refugia*, and floral/faunal mixing[34, 43]. To-date, land use policies have not adequately addressed the root causes of land degradation. Recent trends in land degradation can be linked to imbalances in land distribution, lack of incentives for conservation, insecure tenure and the failure to provide for diversified rural production systems [44].The transboundary characteristics of the lake basin present it with unique opportunities and challenges in the attempts to address land related issues. Decisive and appropriate actions that take into account these facets can significantly reduce vulnerability and increase human security through programs that strengthen coping capacities at all levels[35]. The United Nations Convention to Combat Desertification [45] asserts that land degradation is intricately linked to poverty and that addressing this problem requires the participation of the resource users and, where appropriate, providing them with alternative livelihood options [45].

3.1.3 Inappropriate fishing techniques

Lake Victoria fish stocks and fisheries have undergone remarkable changes over the past 20 years. Signs of overfishing were reported as early as 1970 when catch rates of tilapia dropped from 100 fish per 50m long net (127 mm stretched mesh) to less than 5 fish [46]. As the stocks of Nile Perch increased, the diversity of haplochromines decreased rapidly. The contribution of haplochromines fish biomass in the lake decreased from 80% to less than 1% within a decade from 1970 and1980 [47]. According to the Lake Victoria Fisheries Organization [48], landings of Nile perch have declined despite increasingly intensive fishing efforts[49]. Surveys conducted by LVFO between 2000 and 2006 showed an increase in the number of fishermen operating on the lake, as well as an increase in the number of boats (with and without engines), nets, and hooks (2007). The increased numbers of fishermen and the use of modern catching equipment have caused a dramatic decrease in the stock of Nile perch. Between 1999 and 2001, the stock of Nile perch was estimated at 1.29 million metric tons. For the period between 2005 and 2006, estimated stocks had fallen to 0.82 million metric tons. The stock of Nile perch as a percentage of the entire Lake Victoria fish stock decreased from 59 percent to 39 percent of the total standing stock between 2001 to 2006 [11, 49]. There are about 35 fish fillet processing factories operating within the lakeshore cities which have created high demands for fish landing [7, 50]. Artisanal fishermen cannot compete with commercial fishers because of the poor fishing gear they use [51]. As an alternative, illegal gear such as trawlers and small-mesh-size nets have been used. These destroy breeding sites and catch juvenile fish[52], leaving little opportunity for recovery of the fish population. As a result there has been a decline in Nile perch catches over the past two decades[52, 53] leading to loss of jobs and substantial income losses to local populations and national economies. Following the drastic shifts in species composition and stocks, a number of management measures have been instituted on the lake. Notably among these measures are: the ban on the use beach sane nets and under-sized mesh nets (<127 mm stretched mesh) of 1994, the ban on trawlers in 1996, and the introduction in 2002 of slot size of 50 – 84 cm TL for Nile perch[34].

3.2 Ecologically Related Threats

3.2.1 Eutrophication

Eutrophication primarily caused by poor land use management practices is a serious threat to Lake Victoria. Nutrient loads to the lake associated mainly with atmospheric deposition, natural and biomass burning as well as land runoff, together account for about 90% of phosphorus and 94% of nitrogen input[54]. This has affected water clarity and dissolved oxygen levels. Algal blooms have increased since the 1960's[55]. The filamentous and colonial blue green algae, known for causing hypoxia conditions that occasionally lead to fish kills is now very dominant in Lake Victoria[34]. Large mases of vegetation cover including wetlands and forests have over the years been reclaimed for infrastructure, agriculture, urban settlements as well as for use in building materials, furniture crafting and fuelwood. This has led to considerable nutrient load in the lake from non-point sources. Analysis of sediment cores from the lake show an increasing rate of sedimentation over the past 150 years [15, 38]. While erosion attributed to loss of vegetation cover in and around the lakeshores and river channels is directly contributing to increased suspended solids in the lake; agricultural runoff, untreated soaps, detergents, and chemicals from industrial plants and homesteads within the catchment area are inducing eutrophication.

The use of agrochemicals and resulting runoff at large-scale farms of coffee, tea, cotton, rice maize, sugar and tobacco is increasing in the lake basin[7]. Agricultural runoff is the most significant source of high nitrogen loads in Lake Victoria, accounting for as much as 75% of the nitrogen flow into the lake[56] Consequently, nearly half of the lake floor currently experiences prolonged anoxia for several months of the year, compared to the 1960's when anoxic zones were localized and sporadic [47, 57]. Algal concentrations are three to fivefold greater on the surface waters today than in the 1960's, reflecting higher rates of photosynthesis[55]. The situation has contributed to species decline with the major cause being attributed to land management whose control remains a significant remedy for saving the lake[34, 52].. As a result, algae concentrations are three to five times higher today than in the 1960s[43], and the resulting blooms have become a major problem, blocking sunlight and exacerbating anoxic conditions that harm plant life and result in fish kills. Hundreds of hectares have been cleared for cultivation purposes in Kenya, Rwanda and Burundi, see Table 3 leading to increased soil erosion as well [54].

Table 3: Agricultural Characteristics of the Lake Victoria Basin. Catchment land area (1000 ha)

Catchment Area	Cultivated	None Cultivated	Total
Kenya	1470	3400	4870
Uganda	1400	2100	3500
Tanzania	1500	5540	7040
Rwanda	930	1130	2060
Burundi	670	640	1310
Total	***5970***	***12,810***	***18,780***

Source: Adapted from Odada et *al* 2004

Some rivers, such as the Sio, Sondu, Nyando and Kuja in the Lake Victoria basin Kenya, drain highly productive agricultural areas. In the 22 years the sediment load of river Nyando, increased 7.5 times with turbidity measured at 527 NTU in the rainy season of 2001[38]. Nearly half of Lake Victoria's floor currently experiences prolonged anoxia for several months per year, compared to the 1960s when it was a localized phenomenon [43]. Other indicators are similarly bleak; according to FAO, the Secchi water transparency index declined from five meters in the 1930s to less than one meter in the 1990s [11, 58]. Healthy papyrus wetlands, that prominently featured in the Lake Victoria region, and helped control the effects of nutrient loads as well as sedimentation [59] have in recent years become increasingly degraded, and their ability to continue providing these valuable ecological services has been threatened [12]. The mining of development minerals like sand, clay and marble has only disrupted the ecosystem even further. In Kenya sand harvesting is mainly done 5 -10km away from the lake particularly in Winam and Ahero [52, 60]. Without action, these problems will no doubt worsen in the coming decades, with increasingly adverse impacts on the environment and health of the communities in the Lake Victoria. In addition to environmental consequences, eutrophication also may impact the food and livelihood security of the most impoverished communities living along the lake shore[11].

2.2.2 Proliferation of Alien Species

Fish Species

Numerous literatures have established that the introduction of exotic fish species i.e. Nile perch (*Lates niloticus,)* and Tilapias (*Oreochromis niloticus)* in the 1950's resulted in drastic reduction of nearly 200+ endemic species of fish[2, 7, 53, 61]. This was evidenced by the decrease of haplochromines to fish biomass from 83% in the 1970s to less than 1% in the 1980s [62-65].The native tilapiines.e. *Oreochromis esculentus* and *O. variabilis* were displaced through inter-specific species competition for food, space, and mates by the introduced superior breeds of *O.Niloticus*, *Tilapia zillii*, *T.r.*. The introduction of the Nile perch however, brought with it a complete change in the local fishing economy and distribution of wealth [66]. The original fish community of the lake included at least 300 species, mostly haplochromine cichlids and at least 14 cyprinids[67]. There were more than 20 genera of non-cichlid fishes. The most important commercial tilapiines were *Oreochromis esculentus* [68] and *Oreochromis variabilis* (Boulenger). Haplochromine cichlids and a native cyprinid, Rastrineobola argentea (Pellegrin) were abundant but, because of their small size, they were not originally exploited extensively[67]. Exceptionally high lake levels due to high rainfall, from 1961 to 1964 helped the introduced tilapias to get established[69] and also accelerated eutrophication and other limnological changes [70].Since the 1990s the fishery of Lake Victoria has been dominated by three commercial fish species, Nile perch, *R. argentea* and Nile tilapia [53, 71]. The late 1990s and the early 2000s were dominated by a drastic reduction in catches of Nile perch in the lake and there are indications that if the downward trend is not halted the fishery could be heading for an imminent collapse [72]. However, some studies have postulated that following the decline of the perch, biodiversity is going to increase in the lake as was the case in the 1960s to 1980s[73, 74]. A recovery of native species in the lake was noticed in the early 2000s. Even some haplochromines hitherto thought to be extinct were found in catches[53, 72].

Water Hyacinth

The invasion of the non-indigenous water hyacinth (*Eichhornia crassipes)*, between 1997-1999 caused changes that perhaps were less drastic ecologically but gravely disrupted local economies. Water hyacinth first appeared in Lake Victoria in 1989[75]. By 1995 in the Ugandan waters of Lake Victoria, stationary mats were estimated to cover 2200 ha along 80% of the shoreline; much of the Kenyan Winam (Nyanza) Gulf was covered, as were many other areas around the lake. The weed inhibited fishing, boating, and the decomposing plant material induced anoxic conditions in the lake. The waterweed was found to accumulate high heavy metal levels and to harbor high densities of pathogenic faecal coliforms, streptococci as well as *Salmonella* and *Vibrio* species [2]. Water hyacinth provided feeding and breeding grounds for the tilapia, led to a reduction in beach seining, a common fishing method in shallow waters, allowing the fish time to reproduce and grow[53]. Under the hyacinth, water oxygen levels were as low as 0.01 mgl-1. Nile tilapia has higher tolerance to low oxygen concentrations than Nile perch whose critical dissolved oxygen is 5 mgl-1[63, 72].Water hyacinth disappeared almost completely by the late 1990s. This was due to mechanical and manual removal, changes in hydrological conditions during the 1997–1998 El Niño, ecological succession and the introduction of the *Neochetina eichhorniae* and N. *bruchi* weevils for biological control[76]. However, nutrient enrichment may cause resurgence and it is expected that periodic outbreaks may reoccur [71, 77].

2.3 Water Pollution and Quality Concerns

Both point and non-point source pollution are major problems in the Lake Victoria basin. Important pollution components of the lake include eutrophication, microbiological pollutants, chemical pollutants, and suspended solids. These are a result of direct activities on the lake i.e. untreated municipal sewage, agricultural waste brought in by inflowing rivers, maritime transport waste, as well as runoff and storm waters inflow[35]. Population accelerated the rates of deforestation, agriculture, animal husbandry, industrialization, and wastewater disposal in to the lake, contributing to increased biological productivity during the twentieth century[78]. These changes at the landscape level were superimposed on a warmer and wetter regional climate during the latter half of the century [79, 80]. The result was eutrophication of a pattern familiar in temperate regions [31, 70].Urbanization, along with industrial and agricultural activities around Lake Victoria, have increased significantly over the past three decades[57, 81] resulting in major inputs of nitrogen and phosphorus to Lake Victoria [7, 81, 82]. The quality of Lake Victoria's water has been further exacerbated by large discharges of untreated sewer and chemical wastes from urban centers as well as mycobacterial and nutrient laden runoff from pastoral and agricultural land, shrub-lands, forests and municipal slums. Untreated wastewater from Mwanza City is discharged directly into Lake Victoria via the Mirongo River and Igogo Creek[83], with a total discharge estimated at over two million litres per day [84].The Nakivubo sewage system in Jinja, Uganda, has been reported to discharge semi-treated effluents into the lake at a rate of over 16 million litres per day, see Table 4 [85]. The lack of treatment poses major risks to public health because 70% of the basin population utilizes raw water in some form or another [57]. A study conducted by Kiwango and Wolanski estimated that 80% of the riverine phosphorus entering Lake Victoria comes from municipal and industrial sewage and the dumping of untreated sewage from villages and small settlements [86]. There is evidence that the domestic biological oxygen demand (BOD) exceeds industrial loads in all regions[54]. While policies and regulations prohibiting the direct disposal of untreated waste into the lake exist, they are however not consistently enforced. The microbial contamination of the lake has increased the risk of waterborne diseases outbreaks[87]. Although life expectancy statistics are not available at the basin level, it is likely that in addition to dramatically reducing the standard of living of those who depend on the lake's waters, water pollution also may be reducing their life expectancies[43].

Table 4 : Number of sewered and unsewered urban populations in the Lake Victoria catchment area

Country	Total Population (1000 People)	Sewered Urban population (1000)	Unsewered Urban Population (1000)	Number of towns
Kenya	10,200	390	630	18
Uganda	5,600	210	870	9
Tanzania	5,200	27	340	4
Rwanda	5,900	-	400	5
Burundi	2,800	-	140	4
Total	***29,700***	***627***	***2,380***	***40***

Source: Scheren et *al* 2000 [54]

3.3.1 Mining

Exploitation of mining resources is another aspect that has led to pollution in the Lake Victoria basin. The region is endowed with a variety of minerals; metallic and non-metallic ore deposits such as gold, limestone, copper, iron, silver, soapstone, quartz sand, chromium and lead. Uncoordinated and haphazard prospecting for these minerals, has led to contamination as well degradation of both land and water [35]. Recent studies indicate that high levels of mercury, an essential element used in artisanal gold mining activities is present in the lake due to recent exploration activities mainly in areas such as Geita and Musoma [88-90]. The presence of mercury has been documented in large Nile perch, weighing more than 5-10 kilograms (kg) with concentrations usually exceeding 200 ng/g in fish tissue[91]. Mining activities are not only associated with deforestation but with destruction of the soil surface, exposing open pits in the ground and covering top soil with gravel and sub soils. In some areas land has been abandoned after the mining activities without any attempt at rehabilitation. Several studies have revealed significant levels of Cr, Cu, Cd, Pb, Zn, and Hg in sediment and water samples from Lake Victoria [91-94], with the potential to adversely impact on human health.

3.3.2 Use of Pesticides

Pesticides directly introduced by fishermen or indirectly through runoff from agricultural areas are a public health concern. These have been detected in water and fish samples from Lake Victoria [95-98] see Table 5. The levels detected are much lower than the WHO guidelines for daily intake of drinking water, however, they become significant considering magnification through the food chain [34, 99].The lake phytoplankton community has changed towards dominance of unpalatable and toxic cyanobacteria[99]. It is estimated that there has been a loss of up to 50% of oxygenated water volume in Lake Victoria since 1960s[100].

Table 5: Comparison of pesticide residues in water from river Sio, Nzola and Lake Victoria (μg/kg)

Pesticide	R. Sio (n=9)	R. Nzola (n=9)	Sio Port Beach (n=9)	Marenga Beach (n=9)
α-HCH	3.55-5.16	3.87-6.94	1.81-6.06	0.91-7.78
α-HCH	2.7-4.00	1.34-4.19	0.92-3.59	0.52-233
α-HCH	2.07-18.25	5.56-27.09	6.23-24.54	3.37-23.12
P.P'-DDT	2.56-19.30	14.73-20.42	7.16-12.57	1.62-12.32
O.P'-DDE	3.97-13.37	9.63-10.62	0-6.21	5.15-10.53
P.P'-DDD	9.11-39.54	21.56-24.20	13.16-19.49	10.72-18.91
α-Endosulfan	16.50-25.50	11.04-49.11	5.96-22.47	0.12-13.45
Endosulfan sulphate	11.26-15.56	10.32-25.97	2.88-13.17	6.72-13.06
α-Endosulfan	0.01-0.32	0.002-0.12	0-0.05	0-0.03
Aldrin	6.15-57.32	9.41-27.76	11.71-12.71	11.44-20.78
Dieldrin	22.07-65.48	30.65-51.92	16.03-57.01	11.94-69.55
Endrin	7.07-12.76	14.07-26.86	8.64-18.13	8.00-10.99
Heptachlor	8.25-16.59	17.24-27.99	2.49-10.00	13.76-30.83
Heptachlor e	3.40-40.00	4.06-21.70	3.20-8.76	3.24-6.31
Methoxychlor	2.61-8.13	7.82-37.47	2.52-14.78	3.45-4.41

Source: Madadi 2004

Various researchers have found that heavy metals like copper, zinc, manganese, iron, cadmium, lead and chromium carried out in various sections of the lake generally have higher trace metal concentrations in sediments than water and other living organisms [91, 101]. More so, tropical lakes are especially sensitive to pollution because their naturally lower levels of oxygen, resulting from high regional temperatures, reduce the ability of the lake to absorb pollution loads[43].

3.4 Climate Change

The basin's climate system has changed since the Holocene era [6] and continues to vary spatially and temporally, in part due to human activities, and is projected to continue to change and influence ecosystem change[52]. Concerns regarding the ecological and social impact of potential climate change and variation have been raised by Hulme et *al* [102]. Recent climatic trends for the lake basin have shown 10–40% decreases in precipitation since 1960 [34] and the potential for further decreases and increased air temperatures. Lake Victoria is sensitive to climate change as its water balance is dominated by rainfall and evaporation, with river inflow and outflow making minor contributions[43]. Global warming will lead to higher temperatures estimated to be between 0.2 and 0.5 ºC per decade for Africa [102]. The major effects of climate change on the basin's water systems are as a result of changes in the hydrological cycle, the balance of temperature, and rainfall. Lake Victoria is now 0.5°C warmer than in the 1960s [47, 103]. Maximum temperatures in the region have been progressively increasing over the past four decades. It is also likely that extreme events such as El Niño are being experienced more frequently, and have become more intense in the basin[104]. The 1997 El Niño which saw Lake Victoria level rise by 2.4m [105] was the strongest in the region and caused wide-ranging agricultural, hydrological, ecological, economic and health impacts[106]. Climate change in the lake basin is linked to local processes such as deforestation and burning of vegetation, reduced infiltration and topsoil depletion and soil erosion (Figure 3). It is also a driving force for a number of health problems including malaria epidemics [107, 108]. Dramatic fluctuations in lake water levels have been reported during several time periods. As a general pattern, the lake levels were relatively low—but constant—between 1900 and 1961[27]. Beginning in 1961 with a period of unusually high rainfall, lake levels rose substantially, eventually rising by about two- and one-half meters[109]. Then, beginning in 2000, water levels began to fall once again, eventually declining by as much as two meters[11, 109]. Water levels highly sensitive to changes in rainfall patterns, and especially dependent on the yearly seasonal rains, including the long rains, which occur between March and May, and the short rains, which occur between October and December [27]. Under normal circumstances, outflow is limited primarily to evaporation, which accounts for some 85% of the water leaving the lake[11, 28].

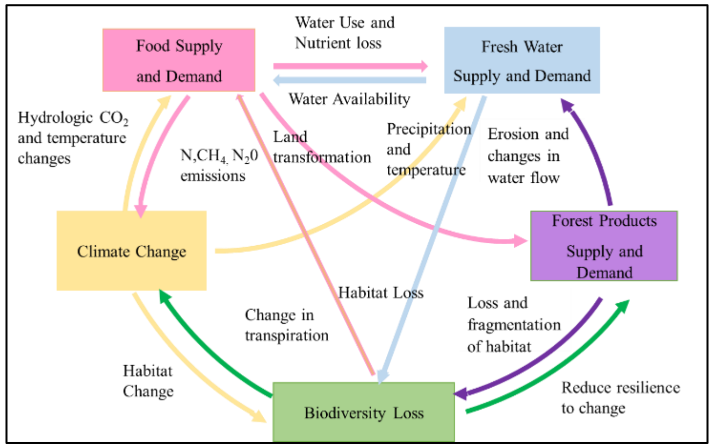

Figure. 1: Drivers and impacts of global climate change
Source: Lake Victoria Basin Environmental Outlook.2006 [34]

A few researchers have used models to show that decreasing precipitation and increasing air temperature are expected to cause decreases in plant, soil, and system carbon as well as plant production, all of which are instrumental in land cover dynamics[33, 110, 111]. Climate change impacts on global and country level agricultural land use also relevant for understanding climate change impacts on ecosystems level changes[112].

IV. Regulatory Frameworks for Lake Victoria

Given its location and importance, the management of Lake Victoria requires institutional and regulatory frameworks that will ensure the sustainable utilization of water resources for the benefit of all riparian countries. The water quality deterioration and loss of biodiversity in Lake Victoria, for example, is a result of weaknesses in current and past management strategies in the three East African riparian states[52]. Lake Victoria continues to be governed by international agreements that were established between the 1920s and 1950s under colonial rule. The agreements are generally geared towards ensuring that Sudan and Egypt, whose economies rely on irrigation schemes, get sufficient water throughout the year [2, 113, 114]. These existing Nile agreements, which were expected to govern the development of Lake Victoria and its catchment, have failed to ensure its protection and sustainable development to Lake Victoria Basin states. Unless there is a comprehensive review of the existing Nile Basin agreements, Lake Victoria may become the source of water conflicts in the region. Negotiations are under way among the ten Nile Basin member states to review the Nile agreements under the Nile Basin Initiative [115]. But how the legal and institutional frameworks proposed will equitably serve the interests of the member states, is a matter for future discussion. A lack of harmony in water and wastewater standards, and different agricultural policies among the three riparian states, further undermines common objectives. The three riparian states have weak economies that cannot support radical changes in food and industrial production as well as in waste management technologies. Thus, their end-of-pipe waste management approaches place significant pressures on the environment and will continue to affect Lake Victoria[116]. However, for now all the riparian states have established national environmental institutions, established by acts of parliament. Uganda and Kenya have cross-sectoral environmental legislation frameworks called the Uganda Environment Management Statute, 1995, and the National Environmental Management and Coordination Act, 1999 (Kenya), respectively. While Uganda and Kenya have had framework environmental legislation since the 1990s, Tanzania has an Environmental Management Act enacted in 2004. Although the organizations empowered under these legislative provisions have been granted the powers to care for the environment, all experience difficulties in executing their powers because of the lack of human, technical and fiscal capacities. As a result, they lack monitoring and enforcement capabilities and are reduced to advisory institutions to their respective governments.

Protocol for the sustainable development of Lake Victoria Basin (2003).

A Protocol on Sustainable Development of Lake Victoria Basin was signed by the three partner states of the East African Community (Kenya, Uganda and Tanzania) on November 29, 2003, and ratified in November, 2004. Article 3 of the Protocol outlined the fourteen areas of cooperation as they relate to conservation and sustainable utilization of the resources of the Basin. Among the areas of cooperation, was, "the sustainable development, management and equitable utilization of water resources" and "the improvement of public health with specific reference to sanitation". Further, Article 33 of the Protocol established the Lake Victoria Basin Commission (LVBC). The LVBC has a mandate to coordinate, promote and facilitate conservation and sustainable utilization of resources in the Basin. It aims to encourage appropriate stakeholder participation in conservation and management of resources at various levels, including at village, local, national and regional levels. It's role, as the "body for the sustainable development and management of the Lake Victoria Basin", involves a broad range of functions including; guidance on implementation of sector projects and programs, promotion of capacity building, institutional development, initiation as well as promotion of programs that target poverty eradication.

V. Conclusion

Managing a transboundary resource like Lake Victoria is complex and requires a long-term strategy that entails capacity building of the resource users, a partnership arrangement between them and their respective governments. However, in practice, many transboundary basins lack the required institutions to prevent and resolve conflicts and to coordinate resource sharing. Integrated water resources management (IWRM) strategies would open opportunities for addressing primary social and economic courses, including poverty alleviation and a way out of the subsistence farming trap and related environmental degradation in the basin. The water and land conservation issues are closely related to rural poverty and vulnerability of inhabitants of the basin. It is necessary for the decision-making mechanisms to take into consideration the differences in the communities within the transboundary basins. By adopting an IWRM approach that is geared to promoting coordinated development and management of resources linking land, water supply as well as demand, while involving all stakeholders and authorities would act as a measure to ease pressure on the degraded land and water basin and let it recover for present and future generational use. Integrated management should include programs/projects in domestic water use, water supply and sanitation for health; small and large-scale agriculture-ranching for food security and income generation; Agro-forestry for income generation, business and ecosystem services; tourism for wildlife conservation and earn foreign exchange; mining and other Agro-industries to add value to harvested natural resources and alternative energy sources. Further research/action is required on the following wider aspects: water-quality assessment; resource inventory, mapping and use, sociocultural issues (encompassing health), agriculture, and education, within the entire lake basin.

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