Journal of Water Resources, Engineering, Management and Policy
DOI:https://doi.org/10.56542/wi.jwempo.v3.i1.a7.2026

Review Article

Safeguarding the Future of Lake Tanganyika: A Review of Environmental and Socioeconomic Sustainability

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Received Date: 23/07/2025 / Published Date: 30/06/2026

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Abstract

Lake Tanganyika is one of the oldest and biggest freshwater lakes in Africa. This lake is facing serious pressure from growing human activity which affect its ecosystem and sustainability. Pollution of the lake which mostly comes from farming runoff and deforestation, along with shifting climate patterns, have steadily damaged the lake's water quality and pushed its diverse ecosystem to the brink. Invasive species keep gaining ground, while small-scale fishing, often careless and unsustainable, threatens native fish and throws the local environment out of balance. This review uses the Drivers-Pressures-State-Impacts-Responses (DPSIR) framework to dig into Lake Tanganyika's sustainability issues, looking at both environmental and socioeconomic angles. Quantitative studies show fish catches have dropped by around 30% over the past forty years. Even more troubling, recent numbers from 2020–2024 reveal another 20% plunge in production. It is clear that quick action is needed. The review pushes for global and local collaboration. When communities implement sustainable fishing practices and establish cross-border conservation agreements, they can mitigate human impacts and facilitate ecosystem recovery. Through the establishment of sustainable fishing quotas and the promotion of eco-tourism, the lake's environmental integrity and economic benefits can be preserved for posterity, contingent upon strengthened cross-border cooperation. This analysis highlights the critical need for sustainable management to ensure the enduring health and socioeconomic viability of the lake and its associated ecosystems.

Keywords· Lake Tanganyika, Human activities, Pollution, Biodiversity loss, Climate change, Transboundary cooperation.

1 Introduction

Lake Tanganyika, located in the Great Rift Valley of East Africa, is one of the oldest and biggest freshwater lakes in the world. It is bordered by Tanzania, the Democratic Republic of Congo (DRC), Burundi, and Zambia (Jovanovska et al., 2023; Takahashi, 2018). This transboundary resource is the second deepest lake in the world, having depths reaching around 1,470 meters, and it contains about 18% of the Earth's freshwater supply (Eggermont et al., 2008; Janzen et al., 2017; Sibomana et al., 2024). The lake is around 673 Km long and has an average width of 50 Km, covering an area of around 32,900 Km^2 (Yu et al., 2024). This lake is fed by many rivers and streams and empties into the Congo River Basin through the Lukuga River (Jarugula & McPhaden,

2023; Karam et al., 2022). Its distinctive hydrological and ecological features are due to the encircling mountains and steep escarpments of its basin (Karam et al., 2023; Ngouadi & Gorbunova, 2023).

The lake is renowned for its exceptional biodiversity. It is the habitat of more than 1,500 species of plants and animals, with a large percentage being endemic (Thomsen et al., 2020; Vanhove et al., 2021). The presence of various species of cichlid fish with different shapes and behaviors make the lake an ideal spot for evolution research. Additionally, the lake offers habitat to many other organisms including mollusks, crustaceans, and various invertebrates (Behrens et al., 2024; Irisarri et al., 2018; Koblmüller et al., 2008; Thomsen et al., 2020). Lake Tanganyika is essential to the livelihoods of millions of people who reside near its edges (Sarvala et al., 2002). This lake is a source of freshwater, nutrition, and income from fishing. It is documented by G. Bulengela (2024) that the lake sustains a major inland fishery in Africa, with fish serving as a main protein source for nearby villages. In addition to that, Lake Tanganyika serves as an important means of transportation, particularly in areas with restricted road systems (Ivory et al., 2021; Phiri et al., 2023).

Human activities have reported to cause considerable environmental impact on Lake Tanganyika. The lake biodiversity and productivity are endangered by these activities including overfishing, pollution, deforestation, and climate change (Phiri et al., 2023). Climate change-induced warming of surface water has decreased nutrient mixing, which results into decreased primary production. These actions decrease the mixing of important nutrients in the lake and increase water stability (O'Reilly et al., 2003; Plisnier et al., 2018). This also cause decrease in oxygen levels in the lakebed habitats. As a result, all these changes pose negative effect on the populations of fish and mollusks in the lake (Cohen et al., 2016).

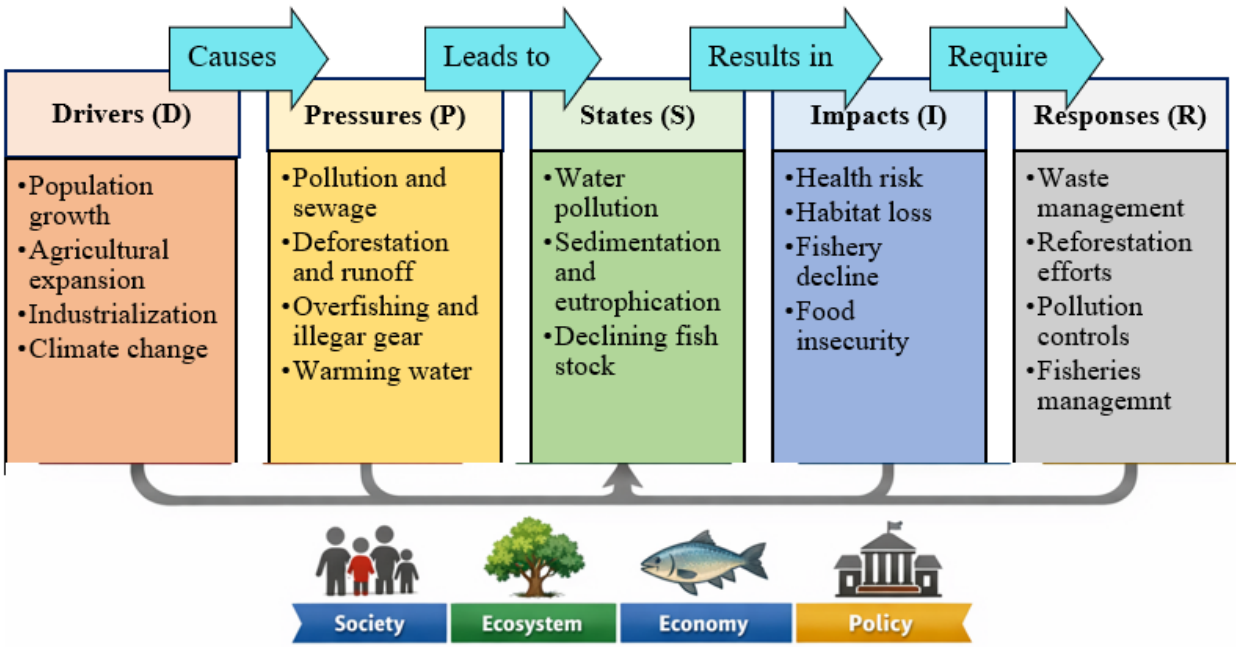

Figure 1: Proposed DPSIR Framework to Lake Tanganyika Challenges

Therefore, the aim of this review is to thoroughly assess sustainability of Lake Tanganyika from environmental and socioeconomic point of view. This research aligns with the Sustainable Development Goals (SDGs), including clean water and sanitation (SDG 6) and life below water (SDG 14).

2 Methodology

The literature on socioeconomic and environmental sustainability of Lake Tanganyika was compiled in this review using a narrative review approach. A complete literature search was carried out utilising databases such as Web of Science, Scopus, PubMed, and Google Scholar. The search method included terms like "Lake Tanganyika," "biodiversity," "pollution," "fisheries management," "climate change impacts," and "transboundary conservation." The inclusion criteria included peer-reviewed journal publications, institutional reports, or theses published in English. These offered quantitative and qualitative data on ecological health and socioeconomic dynamics of the lake. The Drivers-Pressures-State-Impacts-Responses (DPSIR) framework was used as the structural foundation for the analysis. This allowed for a systematic classification of driving forces such as population growth, pressures such as pollution, state changes, such as shifts in water quality, impacts, such as biodiversity loss, and responses, such as policy measures. This technique proven essential in identifying knowledge gaps and gathering research outputs from multiple academic fields.

Table 1: Temporal Trends in Lake Tanganyika Fishery Yields (1990–2024)

Time Period	Estimated Annual Catch	Trend	Primary Drivers of Change	Key Species Affected
Pre-1990s	150,000 – 200,000 Metric Tonnes (MT)	Stable / High	Low fishing pressure; optimal thermal conditions	*Lates stappersii*, *Stolothrissa tanganicae*
Around 2011	110,000 – 120,000 MT	Declining (~30% drop)	Onset of climate warming; reduced nutrient mixing	General pelagic stock decline
Recent Estimates	<100,000 MT	Continued Decline	Illegal gear; sedimentation; habitat loss	*L. stappersii* (Migebuka), *S. tanganicae* (Dagaa)
2020–2024	~80,000 MT (Projected)	Sharp Decline (~20% drop)	Post-COVID demand; intensified effort; climate stress	Collapse of key species stocks

Sources: (Deo Mushagalusa et al., 2024; FAO, 2025; Phiri et al., 2023).

3 Human Activities Affecting Ecology of Lake Tanganyika

Lake Tanganyika is experiencing a complex socio-ecological challenge. Figure 1 presents DPSIR framework used to analyze the causal linkages between human activities and environmental degradation (Burkhard & Müller, 2008).

3.1 Population Growth and Urbanization

The ecology of Lake Tanganyika is significantly affected by population growth and urbanization. Both of these influence pollution, habitat degradation, and changes in biodiversity (Bonar et al., 2022). It has been

reported that more than 10 million people reside in the Lake Tanganyika region. These people make around 43 individuals per square kilometer population density. With a growth rate of nearly 4% per year, this increases pressure on land and water resources (Ryan et al., 2017). Rapid urbanization has caused discharge and accumulated of residential waste into the lake (Niyongabo et al., 2024; Wenban-Smith, 2015). According to research findings, urban areas around the lake contribute more on water quality as compared to

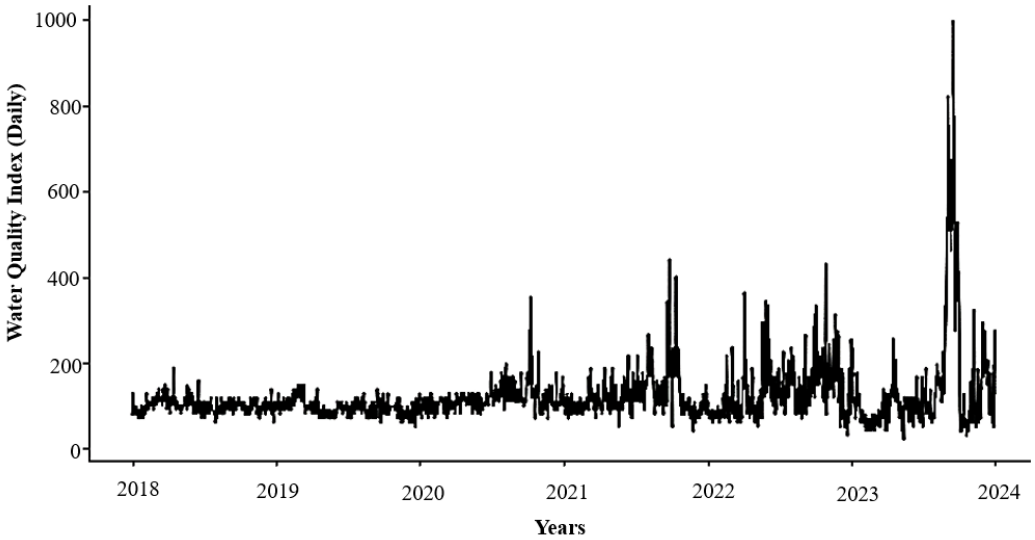

Figure 2: Water Quality Index of Lake Tanganyika (2018-2024) showing a progressive decline in water quality, calculated using WAWQI methods. Higher values indicate poorer water quality Source: (Niyongabo et al., 2024).

Figure 3: Sewage discharge into Lake Tanganyika from an industrial outlet in Burundi, Source: (Niyoyitungiye, 2019).

rural areas. In urban areas, land use types account for 78-96% of the variance in water quality contrary to rural areas, where the figure ranges from 21-70% (Yu et al., 2024). The discharge of untreated sewage and solid waste into the lake has been reported. This practice is associated with significant population growth and inadequate waste management (Miller & Soreghan, 2023).

Introduction of wastes into the lake adds organic matter, nutrients and plastic into the lake, which endanger aquatic species and enters the food chain (Bonar et al., 2022; Wang et al., 2024). Habitat degradation together with accumulation of pollutants endanger the unique biodiversity of the lake (Moshi et al., 2022). Studies have revealed drastic decline of fish stocks due to overfishing and habitat degradation The annual fish catches currently of around 200,000 tonnes reflects a decline from historical levels (G. Bulengela et al., 2020; G. S. Bulengela et al., 2020; Niyoyitungiye, 2020). Establishing water quality monitoring programs, designating buffer zones to prevent development near the lake, and improving waste management systems to reduce pollution are among the necessary strategies for sustainable management.

3.2 Deforestation and Land Use Changes

Figure 4: Flooded areas at Gatumba, Burundi. **Source** (Lorraine, 2024)

Deforestation and land use changes along the lake have significantly impacted the lake ecology. These influence the water quality, biodiversity, and sedimentation patterns (Lawrence et al., 2023; Phiri et al., 2023). Deforestation in the lake catchment is driven

by agricultural expansion and logging. While studies generally agree on the impacts to the lake, there is some variation in estimated sedimentation rates. For instance, McGlue et al. (2021) noted unprecedented accumulation rates in deforested areas compared to historical records, whereas earlier work by Cohen et al. (2005) emphasized the linkage to specific land-use changes. The increase in sedimentation reduces water clarity and alters habitat quality. This in return adversely affect the diversity and densities of aquatic species.

According to paleolimnological research findings, significant deforestation occurred as early as the late 18th century, with intensified impacts in the mid-20th century (Cohen et al., 2005; Ivory et al., 2021). A study by Kashaigili & Majaliwa (2010) investigated land use temporal-spatial features in the riparian zone of the lake. The findings of this study show a significant transition from forestland to farmland. Another study investigated the changes in land use within the Malagarasi River Basin. This study reported that from 1984 to 2001 the woodland and wetland vegetation covers have decreased by 0.09% and 2.51% annually respectively (Kashaigili & Majaliwa, 2010). Adopting sustainable agriculture practices and reforestation is important for mitigating these negative impacts.

3.3 Overfishing and Unsustainable Fisheries

Another challenge impacting the ecology of the lake is overfishing and unsustainable fishing practices. In times of conflict, especially in the Democratic Republic of the Congo (DRC), when displacement and instability have increased fishing demand, fisheries provide an essential "safety net" role (Namwira et al., 2024). Typical illegal practices include using mosquito nets, fishing from restricted landing sites, and fishing without a licence (De Keyzer et al., 2020). These practices contributes significantly in substantial decreases in fish populations and biodiversity. The results from the 2025 fish stock assessment conducted by FAO, TAFIRI, and LTA shows that there is a drop in production by nearly 20% between 2020 and 2024 (FAO, 2025). This information updates the previous estimates that showed catches nearly halving over three decades. Apart from overfishing and illegal fishing practices, the impacts of climate change also contribute to this decline (Lawrence et al., 2023; Phiri et al., 2023). It has been reported that the populations of key species in the lake such as *Lates stappersii* and *Stolothrissa tanganicae* have significantly decreased (Van der Knaap, Kamitenga, et al., 2014; Wabike, 2012). Despite the Tanzanian government's enforcement legislation restricting beach seines, resistance is still present due to significance of these traditional practices (Brehm et al., 2022). Recent data shows a significant decrease in fish production levels in Lake Tanganyika as presented in Table 1.

3.4 Pollution from Domestic and Industrial Sources

Domestic waste, including household waste and wastewater, is directly dumped into Lake Tanganyika without any treatment (Niyongabo et al., 2023). The daily water quality index (WQI) trends for Lake Tanganyika from 2018 to 2024 (Figure 2) were established using WAWQI computation methods. According to this method, water quality is classified as outstanding (0-25), good (26–50), poor (51–75), very poor (76–100), and unsuitable for drinking (>100) (Tyagi et al., 2020). The trend of WQI indicates a progressive decline in overall water quality due to continual pollution (Niyongabo et al., 2024).

Recent research demonstrated the presence of Escherichia coli bacteria, with an average level of 1,350 CFU/100 ml in Tanganyika Lake (Niyoyitungiye, 2020). During the rainy season, residents drinking lake water reported outbreaks of waterborne cholera, evidence of fecal contamination (Niyongabo et al., 2023). Different heavy metals have been discharged into the lake as a result of increased industrial activities. According to the recent studies, there is significant spatial variations in heavy metal levels, with the highest levels found near urban areas

(Bonar et al., 2022; Wang et al., 2024). Heavy metals contamination poses health risks to humans and aquatic life (Shen et al., 2019; Yozukmaz & Yabanlı, 2023).

An example of sewage discharge into the lake is presented in Figure 3. These practices, which are categorized as point-source pollution, threatens both aquatic life and human health by introducing heavy metals and organic pollutants in water (Bonar et al., 2022; Yu et al., 2024).

Table 2: Chronology of key conservation initiatives and projects

Period	Initiative / Agency	Focus Area	Key Outcomes / Contributions
1992	Rio Earth Summit Follow-up	Global Agenda	Initiated international discourse on Lake conservation.
1995–2000	Lake Tanganyika Biodiversity Project (LTBP) (UNDP/GEF)	Biodiversity & Sedimentation	Provided baseline data on pollution, fisheries, and biodiversity.
2003	Convention on Sustainable Management	Transboundary Policy	Signed by Tanzania, DRC, Burundi, Zambia.
2007	Lake Tanganyika Authority (LTA) Establishment	Governance	Ratification of convention; Secretariat established (2009).
2002–2010	Lake Tanganyika Management Planning Project (LTMPP)	Cross-border Collaboration	Enhanced regional cooperation; raised community awareness.
2018–2022	TAKIWAMA Project (EU/AfricaDev)	Water Monitoring	Introduced advanced water monitoring and citizen science data.
2023–Ongoing	TAKIWAMA Phase II	Data Integration	Continued monitoring of nutrient pollution dynamics.
2025 (Launched Feb)	UNEP-GEF Project: Biodiversity Conservation & Water Security	Integrated Land-Water Mgmt	Targets transboundary threats; integrates land-use with water security.

3.5 Invasive Species

Biodiversity and ecosystem balance of the lake is impacted by a growing threat from invasive species. Invasive species which are often introduced through human activities are commonly characterized by outcompeting the native species and alter habitats (Havel et al., 2015; Mayfield et al., 2021; Reynolds & Aldridge, 2021). A good example is water hyacinth (*Eichhornia crassipes*) which is a prominent invasive plant in the lake. The rapid expansion of water hyacinth can lead to the loss of vital fish habitats and reduced oxygen levels in water (Phiri et al., 2023). Another example is *Mimosa pigra* L. This species poses a threat to native aquatic plants by outcompeting them for resources (Witt et al., 2020). Longitudinal data on the precise impacts of invasive species on Lake Tanganyika are still inadequate despite the fact that controlling them is necessary.

4 State and Impact of the Ecosystem

The lake is currently facing significant environmental degradation and, in some areas, rapid biodiversity loss. This is due to cumulative impacts of climate change, pollution, and overfishing (Cohen et al., 2016; S. A. Kraemer et al., 2019). Studies show that the temperature of surface water at Lake Tanganyika have increased by about 1.3 °C since the early 1900s/late 19th century, which exceeds typical global lake averages (Verburga & Hecky, 2009). Recent 3-D hydrodynamic research also indicates that deeper waters (>150 m) warmed by up to 0.4 °C between 2001 and 2020, showing that even below the surface the lake is warming (Kamulali et al., 2025). Long-term limnological studies highlight that the lake is warming at high rate when compared to many other lakes and has led to increased stratification of the water column

(B. M. Kraemer et al., 2015). This thermal acceleration strengthens stratification, effectively blocking the vital upwelling of nutrients from deep layers. Consequently, the lake has experienced about 20% decrease in phytoplankton (algal) growth, signaling a bottom-up collapse of the food web base (O'Reilly et al., 2003). Cohen et al. (2016) found that climate warming and stronger stratification have reduced lake mixing and shrunk the oxygenized benthic habitat by about 38 % in study areas of Lake Tanganyika, which has negatively affected bottom-dwelling organisms and endemic species. Visual indicators also show degrading health of the lake. Pollution from runoff and plastics have caused decrease in water transparency (Secchi depth) in important areas from 270 cm in 2016 to about 200 cm in 2022 (O'Reilly et al., 2003). In 2024 the lake reached unprecedented water levels, measuring 777.32 meters above sea level. This increase is estimated to be around 2.5 meters during the previous 50 years. The associated extreme flood levels have severely damaged coastal cities, resulting in significant humanitarian and socioeconomic losses (Lusaka Times, 2024). At Kalemie (DRC) it directly impacted over 12,000 households and flooded more than 10,000 houses. International ports were submerged for days, halting lake transport and cutting off road access to surrounding areas. At Bujumbura and Gatumba (Burundi) the entire neighborhoods along a 13-kilometer stretch of the coast in Bujumbura were forced to evacuate (Desire, 2024). In the nearby town of Gatumba, the rising lake prevented the Rusizi River from draining properly, causing water to stagnate or flow backward, displacing nearly 100,000 people in 2024. Infrastructure destruction including offices, power lines, and water intake systems—accounts for an estimated 67% of the total damage in affected regions (Lorraine, 2024).

5 Conservation and Management Efforts (Responses)

Efforts to conserve and manage Lake Tanganyika have successfully preserved its diverse range of plant and animal species. These measures include the establishment of protected areas and the implementation of sustainable fishing practices. The agreements include cooperation between the countries surrounding the lake to regulate fishing activities and prevent excessive use of resources that could harm the ecosystem. These efforts have been growing since the early 1990s. In 1992, following the Rio de Janeiro meeting, efforts were made to address the lake's conservation challenges (Odada et al., 2003). With the help of the UNDP/GEF, in 1995 the Lake Tanganyika Biodiversity Project was established with the aim of solving the main challenges of the lake, including overfishing, pollution, excessive sedimentation, and habitat degradation (Njiru et al., 2018; Ntiba et al., 2001). The project's three main outputs included five special studies that provided baseline data on the potential threats in each of the lake's riparian states. These studies primarily focused on sediments, pollution, fishing practices, biodiversity, socioeconomics, and educational campaigns to raise awareness. The results of these studies were intended to assist devise steps to ensure the sustainability of the lake (Nkotagu, 2008).

A comprehensive fishery management plan for Lake Tanganyika was developed, which included a Transboundary Diagnostic Analysis (TDA) and a Strategic Action Programme (SAP). As a result of these efforts, the Convention for the Sustainable Management of Lake Tanganyika was signed in 2003, ratified in November 2007, and the Lake Tanganyika Authority (LTA) was established. In January 2009, the LTA Secretariat started its functions (Van der Knaap et al., 2014). The LTA serves to enhance collaboration between riparian countries, coordinate the Convention's implementation, and advance the sustainable management of Lake Tanganyika (Plisnier et al., 2018). The establishment of the LTA was a key step in ensuring the long-term health and productivity of the lake's fishery (Njiru et al., 2018; Ntiba et al., 2001). The treaty seeks to address concerns including as overfishing, pollution, and habitat degradation in order to protect the long-term health of the lake and its surrounding ecosystems (Nkotagu, 2008). In addition, continued efforts are being undertaken to persuade all riparian governments to fully implement and enforce the convention's provisions for the benefit of current

and future generations (Scheumann et al., 2006). The convention also includes guidelines for monitoring and research to evaluate the effectiveness of conservation efforts and make any needed changes. By working together, the countries bordering Lake Tanganyika hope to preserve the unique biodiversity of the lake for years to come (Hasbaia, 2020). These initiatives and projects have been summarized in Table 3

The Lake Tanganyika Management Planning Project was initiated in 2002 under UNDP/GEF support to address threats to the lake's ecosystem, such as sedimentation, pollution, and overfishing. The project emphasized cross-border collaboration among riparian countries for effective resource management and aimed to enhance sustainable fishing practices and promote conservation efforts. By involving all riparian countries, the LTMPP created a comprehensive approach to safeguard the lake's ecosystem for future generations. It also raised awareness among local communities about the importance of preserving Lake Tanganyika's biodiversity and sustainable resource management, encouraging people to play an active role in protecting the lake and its resources (Nkotagu, 2008). Similar efforts by Food and Agricultural Organizations (FAO) and Finnish International Development Agency (FINNIDA) through the Lake Tanganyika Research Project (LTR) were undertaken to assess the fisheries potential of the lake. The project concluded that the decline in fish production in the lake is due to fishing pressure and other human-related activities. It was noted that the ongoing climate change contributes to the decline in fish abundance due to the lengthening and severity of the dry season, which leads to increased runoff and sedimentation in the lake, decreasing overall productivity (Mölsä et al., 1999).

In a significant development, the UNEP-GEF project "Biodiversity Conservation, Sustainable Land Management, and Enhanced Water Security in Lake Tanganyika Basin" was launched in February 2025. This initiative focuses on transboundary threats, aiming to integrate land management with water security to reduce sediment loading at the watershed level.

6 Recommendations

In order to guarantee the future of Lake Tanganyika, the countries along the lake have to take a step further from mere policy agreements towards a thorough, integrated action.

i) For starters, the cross, border governance has to be strengthened without further delay. The Lake Tanganyika Authority (LTA) should secure a committed, long, term funding source that would allow it to carry out a unified monitoring system for combatting illegal fishing and enforcing the rules along the different borders.

ii) Second, management needs to take a comprehensive "ridge, to, reef" approach. Tackling sedimentation is all about strictly enforcing riverbank buffer zones and reforesting huge areas in critical catchments such as the Malagarasi Basin. At the same time, towns should put a higher priority on wastewater infrastructure by changing the existing ones so that the domestic and industrial effluent can be treated. Thus, the problem of heavy metals and organic pollution which threatens both biodiversity and human health is being dealt with right at the source.

iii) Thirdly, the fisheries ought to be resilient to climate change. Considering the facts that production has decreased by 30%, the fishing quotas should be flexible and directly related to the latest fish stock assessments. Nevertheless, ecological concerns are not enough, the economy also needs to be diversified. Countries need to put money into attracting tourists interested in nature and into fish farming that is good for the environment so that the situation of the wild stocks can be relieved and at the same time more ways to make a living be given to the communities that are at risk.

iv) Fourth, the protection needs to be based on science. Increasing mapping the seafloor of

geophysical features will also make it possible to track sedimentation hotspots in real time. Lastly, governance ought to be participatory. By officially incorporating Indigenous and Local Ecological Knowledge (LEK) into the decision, making process, it is ensured that the rules are both scientifically robust and culturally acceptable. This well, rounded approach not only helps the locals to live in harmony with nature but also commits to the sustainability of earth on a global scale, thus preserving the huge ecological and socioeconomic value of the lake.

7 Conclusion

The situation of Lake Tanganyika calls for intervention. Climate change happens faster than ever; pollution has been going on for a long time and there are very few cases when nature has not been overexploited. Besides, the ecological resilience of the ancient and very old lake has been severely eroded to accommodate these factors. The evidence of the decline is very clear: fish stocks and water quality have deteriorated to such an extent that the survival of the local people who depend on these waters has been put in jeopardy. There is no doubt that this is a very serious problem, however it is not the end of the world. The establishment of the Lake Tanganyika Authority and the recent experiments started by the 2025 UNEP, GEF project are just some of the reasons why it is still possible to save the lake. But, just having initiatives on the paper is not enough; this must be translated into actions. A rapid political commitment, a strong financial backing, and a clear move towards cross, border and local community, based governance are needed. In order to ensure the safety of Lake Tanganyika, the riparian nations should adopt the integrated, flexible management approaches recommended in this paper to continue enjoying the habitat with all its biodiversity and resources. It is in our hands to make the decision today that will determine the future of the lake.

Acknowledgements: I wish to thank the University of Dodoma (UDOM) for material support during preparation of the manuscript.

Funding: No funding was received for this work.

Conflict of Interest: The authors declare no conflict of interest.

Authors' Contribution: P.K conceived the study; analyzed the data; wrote the manuscript, made revisions.

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