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Climate Change, Ecology and Management of Tropical Floodplain Lakes: A review

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ABSTRACT

The dreadful condition of the environment and the frequent occurrence of natural disasters have been a central concern in the policy debate over climate change. More challenging is the capacity of man and the entire system to avoid, alleviate and recuperate from the climatic hazards. These issues make it very difficult to predict and monitor environmental changes. The trend of climate change resulting from global warming has also affected the ecology of the tropical floodplain lakes invariably in recent years. Decrease in rainfall, atmospheric humidity and rise in temperature have affected water levels in tropical floodplain lakes. Consequent upon this, some tropical floodplain lakes have faced severe evaporation, turning more salty and eventually leading to loss of biota. Considerably, change in the climate tends to alter the timing and frequency of rainfall, which will have serious consequence on the ecology of floodplain lakes.

Keywords: climate change, Floodplain Lake, ecosystem, water resources, greenhouse gas

1. INTRODUCTION

Climate change refers to long term shifts or changes in the patterns of various climatic elements. It involves changes in the annual averages of temperature and precipitation for a considerable period of time usually, not bellow a decade. The elements of climate may include temperature, precipitation, humidity, wind and seasons. Climate is a function of radiation of the sun and its prevailing effect on the atmosphere. Besides this however, climate can also be influenced by the intricate structure and disposition of the atmosphere and by the ways in which it transports heat. Climate has profound effects on vegetation and animal life, including humans (Fairbridge, 2009). It plays statistically significant roles in many physiological processes, conception and growth to health and disease.

It is however, quite disgusting that humans in turn alter the designed pattern of climate and now fight to contend the outraging consequences. These climate patterns are fundamental in determining the effectiveness of natural ecosystems, economy and cultural aspect of human life that revolve round them. These systems that are tied to climate react over any slight change in climate with direct consequence on food production and availability, how people, plants and animals live, water availability and uses, and disease outbreak (Ebere & Blessing, 2021; Igben, 2021; Beshir et al., 2021). For instance, a change in the timing and

frequency of rains or temperature alter a set-induced biological clock; when plants bloom and set fruits (Sharma & Singh, 2021), when fish spawn or migrate, when insects hatch and when streams are enhanced with nutrient. This can substantively affect a long time existing patterns of event such as crop pollination, food for migrating birds, spawning of fish, water availability for domestic and agricultural uses, forest sustainability and many other related aspects of life (Tadesse & Dereje, 2018).

1.1. The Floodplain Lake

Tropical floodplain lakes which are abundant along many unregulated tropical rivers (Welcome 1979), experience distinct seasonal cycles that are governed by the annual rise and fall of river discharges. During the period of low discharge, these lakes often decrease greatly in size and depth; some of the lakes dry up completely, while others are permanent. Due to low water level during the dry season, permanent floodplain lakes are likely to mix frequently (often daily), and to have relatively uniform temperature and oxygen concentrations throughout the water column (Maclntrye and Melack, 1984; Tundisi et al., 1984; Tundisi and Matsumura-Tundisi, 1984; Harmilton and Lewis, 1987). At the same time, transparency is often very low and nutrient concentrations can be high because, bottom sediments are frequently re-suspended (Marlier, 1967; Schmidt, 1973b). At high discharge, rivers inundate shallow floodplain lakes and consequently, depth, area and volume increase.

Floodplain lakes can be very productive, particularly in relation to their associated rivers (Sioli, 1975; Welcome, 1979). Nutrients from the river stimulate production, part of which passes as biomass to the river. Floodplain contributions of zooplankton to the main river channel depend partly upon the degree of synchronization of production and transport between the floodplain and the river.

2. CAUSES OF CLIMATE CHANGE

Climate change can be attributed to natural variability or may be as a result of anthropogenic activity (IPCC, 2007), consequent upon the complexity of the climate system. In 2007 through the report of the IPCC to the United Nations, it was declared that the well noted warming of the globe in the past 50-60 years is a product of human activities basically, in increasing the concentrations of "heat trapping" gases such as carbon dioxide in the earth's atmosphere.

2.1. Greenhouse Gases

The primary greenhouse gases are Carbon dioxide (CO_2), Nitrous oxide (N_2O), Methane (CH_4), Ozone (O_3) etc. Greenhouse gases have the characteristics of retaining the radiant energy provided to the earth by the sun in a process known as "greenhouse effect". One of the most notable ways people contribute to greenhouse gases is by burning fossil fuels. People make of use coal, oil, and natural gas to generate electricity, heat our homes, power our factories and run our cars.

Fossil burning seems to be the most common way of adding to the concentration of CO_2 in the atmosphere. In the past 20 years, the total CO_2 concentration in the atmosphere has been traced down to anthropogenic emission through the use of fossil fuel for energy and land use practices, especially, deforestation (Zella & Norah, 2019).

In the recent time, almost all CH_4 emissions are being attributed to human activities. The most common sources include use of fossil fuels, decaying animal dungs, rice swamps, agriculture and landfills). Additionally, the increasing emissions of Carbon monoxide (CO) have been widely identified as the reason for increase in the rate of CH_4 concentration in the atmosphere. About a third of N_2O emissions are also anthropogenic (e.g., agricultural soil, animal feedlots and chemical industry).

Some examples of activities that contribute to greenhouse gas levels are summarized as follows:

- Burning fossil fuel – oil, gasoline, gas and coal
- Industrial processes and mining
- Landfills, septic and sewage systems
- Agricultural practices, fertilizer and manure management
- Land use practices, deforestation

2.2. Aerosols

Fuel combustion and to some extend agriculture and industrial processes, release gases, liquid particles and tiny solid soot called aerosols that can remain suspended in the atmosphere for years. Aerosols contribute to global warming in various ways. For instance, the black soot that can be produced by combusting engine and during the burning of some type of biomass can absorb heat from the sun, retain it and then warm the atmosphere. Humans contribute to the availability of aerosols through burning of

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biomass and fossil fuel. The most notable ways through which man can increase the concentration of aerosol are burning of biomass and fossil fuel.

Apart from its known direct radiative forcing, aerosols are also characterized with an indirect radiative forcing through their effects on clouds. The indirect radioactive forcing though, of very uncertain magnitude is usually negative.

2.3. Change in land use

Agriculture is one of the most recognized environmentally destructive and disruptive land-use practices. In an attempt to meet the increasing demand for food in the world, many forested areas have been converted to farmland in a practice called "*deforestation*". Trees play strategic role in Carbon Capture. Very important way of keeping carbon dioxide emission from circulation in the atmosphere is to encourage tree planting and preservation. Trees, especially fast growing ones, have the ability to sink great deal of CO_2 from circulation in the atmosphere and accumulate it as carbon atom in new wood. Forests in the tropics are continually converted to other uses visa-a-vis farming, cattle rearing and housing development. When woodlands and forests are cleared for farming and the woods taken for firewood, or burnt as garbage, stored carbons are released back as CO_2 into the atmosphere. Larger scale changes in terrestrial vegetation may accompany climate change particularly where droughts and seasonal water limitations increase to the point where forests are replaced by grasslands.

2.4. Natural factors

Data simulation has been used to propose the pattern of intensification of solar effect on climate though; it is yet to receive enough rigorous theoretical and observational backing. There have also been reports of aerosols originating from volcanic eruptions in the stratosphere which are capable of activating negative forcing that can last a few years. Several major eruptions were recorded between 1880 to1920 and 1960 to 1991. The combined changes in relative to radiative forcing of the two major natural factors (solar radiation and volcanic aerosols) are predicted to be negative for the past two decades.

3. CLIMATE CHANGE AND HYDROLOGICAL CYCLE

Hydrological system depends wholly on the radiant energy the earth receives from the sun to operate. Hence, the sunlight energy that reaches the earth surface drives the hydrological cycle. Consequently, when the amount of radiation from the sun trapped in the atmosphere increases, it intensifies the cycle and alters precipitation patterns. These changes will result in increased floods and drought which will have significant impact on the availability of freshwater. Meanwhile, the excessive rise in temperature can also create more problems in that, melting of glacier will ensure sea rise and exacerbate flood incidence.

Warmer average global temperature will mean increase in evaporation rate. Warmer atmosphere tends to hold more moisture aloft which can be released at its saturation point as precipitation, increasing the potential for flooding. In the tropical region however, even a slight increase in temperatures will lead to greater loss of moisture, exacerbating drought and desert encroachment. When there is less precipitation with rise in temperatures occurring concurrently with the associated increase in evaporation, there will be threat to the availability of water resources and can result in a vicious cycle. In sub-Saharan Africa, for instance, decrease in amount and frequency of rainfall, long period of drought are already a serious concern and are predicted to become more widespread.

Thermal expansion of oceans and melting of glacier as a result of rise in temperature will lead to increase in sea levels. Change in sea levels will enhance coastal erosion, and flooding of marshlands and lowlands.

4. ECOLOGY AND CHARACTERISTICS OF TROPICAL FLOODPLAIN LAKE

Shallow lakes rather than deep freshwater lakes, are the feature of the tropical topography. These shallow lake types are mainly susceptible to a drying climate. Tropical lakes are far less numerous than temperate lakes because lakes of glacial origin are rare in the tropics. Efficiency of energy transfer appears to be low in many tropical lakes (Schmidt, 1973). Tropical floodplain lakes are seriously threatened by the trend of climate change, as they are mostly shallow and greatly rely on regular inputs from feeder streams, run-off and groundwater to maintain their water levels. Climate change is likely to considerably affect the timing and regularity of these inputs, which may have serious consequences on the natural balance of the lakes. Tropical lakes are valuable ecosystem but their sustainable management in the face of climate change will be very demanding. The protection of lake ecosystems will require policy makers to focus on its environmental value and where adaptive management measures will be most successful.

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5. CLIMATE CHANGE & THE ECOLOGY OF TROPICAL FLOODPLAIN LAKES

Climate change will have great consequence on the ecology and existence of tropical floodplain lakes. Nijssen *et al*. (2001) suggested that climate change projection estimate for Lake Victoria (a tropical floodplain lake) is that the average annual temperature will rise between 0.3 and 160^0C by 2030. In addition to a broad drift of global warming, the frequency of severe temperature is also going to prevail (Nijssen *et al*., 2001).

5.1. Effects of change in water temperature

Increase in average temperature will probably have implicit effects on floodplain lake ecosystems. Drastic change in temperature may lead to change in community structure and composition of plankton, fish and even benthos, as species reach the limit of their temperature tolerance and are gradually survived by those that can tolerate warmer temperature. Upland lakes ecosystems are particular vulnerable, as most species are already at the confines of their temperature tolerance. Other impending challenges to the ecosystem is that aquatic insects may breed faster in the warmer water and emerge earlier in the season and become threat to life. Though, not every individual species may respond to these changes in the same manner and at the same speed, some species may multiply fast enough and increase in number faster than their food source and therefore, may not survive due to pressure on the carrying capacity of the entire ecosystem or inadequate food source to prey on. Rise in temperature may also alter the rate of some important microbial processes in Lake Substratum. This can modulate the biogeochemistry of the lake Ecosystem. These responses to rise in temperature can significantly bring alterations to the food webs and performances of the entire lake ecosystems. Faster growth rates and consequently earlier establishment of algal bloom are also likely. Availability of dissolved oxygen will drastically reduce in the spate of increase in temperature as rise in temperature reduces oxygen solubility (Nwinyimagu *et al*., 2016), a condition that can lead to anoxia. Fish and many resident biological organisms may find it more challenging to subsist, more especially, in the summer periods. Lakes already contending with stressors such as changes in water regime and land use may likely face more vigorous effect of decreased oxygen levels. Increased temperature coupled with change in climate can possibly affect the distribution and density of dangerous pest species. Consequent upon this, the pest species may find the condition favorably and thence, become more successful or emerge in new environments. Increased temperature will also change the patterns of thermal stratification and overturn that control the efficiency of subterranean lakes. Temperature and mixing can also affect photosynthesis.

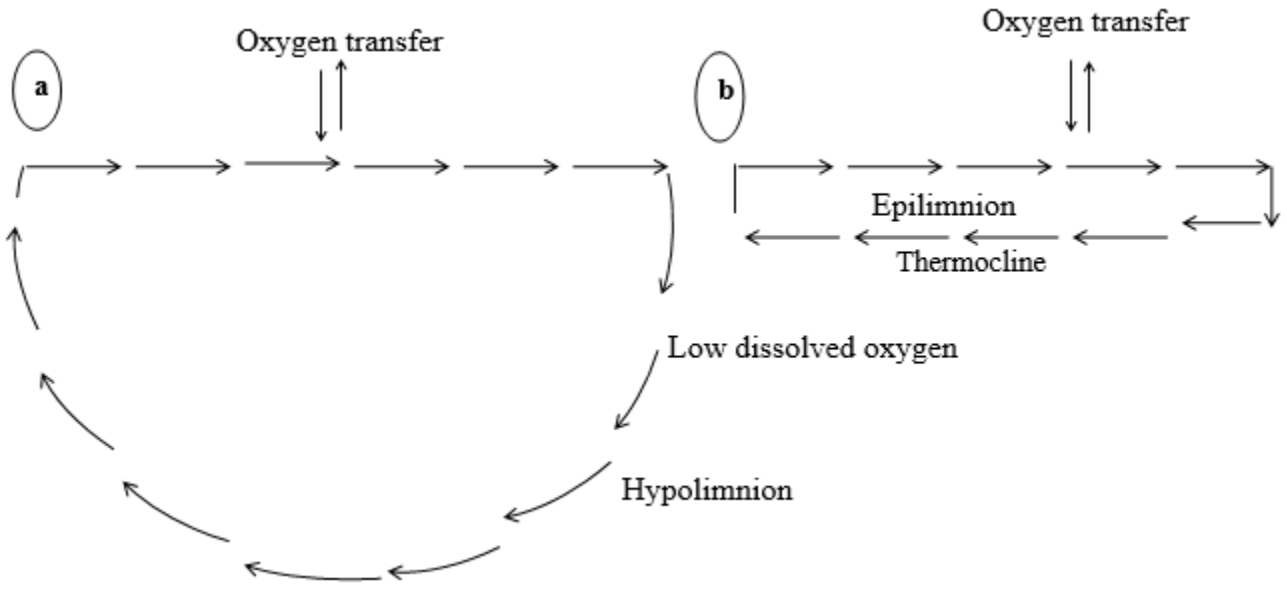

Fig 1: patterns of thermal stratification in lakes.

(a): a well-mixed lake with oxygen transfer occurring throughout the whole water column.

(b): stratification into layers with the hypolimnion (lower layer) having low dissolved oxygen. (State of Victoria, 2006)

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5.2. Effects of low rainfall

There is an indication that climate change may possibly reduce the average annual rainfall. Reduction in the average annual rainfall will bring about low water inputs to the lakes from feeder streams, low runoff from catchments and ground water recharges. This will ensure reduction in lake levels. The severity of reduced rainfall will be more obvious in the Northern and Western of the tropics where many lakes and floodplains are already threatened. These shallow systems characterizing tropical floodplain lakes make them more vulnerable to changes in climate. Some of the lakes are already at very low levels while many more lakes would dry up naturally in the near future. Climate change also indicates that they may remain dry forever.

Tropical floodplain lakes are particularly affected by lower rainfall. This is because, reduction in the frequency and volume of average annual rainfall possibly affect river flows. This means, the periods between fillings for those lakes are likely to be longer as a result of loss of connections between rivers and the lakes. This may eventually deepen the inability of aquatic organism to recuperate because the viability of eggs, seeds and resting stage reduce with increase in time between fillings.

5.3. The Effects of Drought, storms and Bushfire

Climate change may also intensify the occurrence of extreme situations such as droughts, storms and bushfires. Though, droughts may be seen as natural features of the tropical climate, the pliability of Lake Biota to excessive drought is in obscurity. Drought cause shallow lakes to absorb heat rapidly by increasing large surface area – to – depth ratios which can make them to dry up more quickly. The influx of sediments with metals and chemical nutrients are the most notable storm events associated with lakes. The likelihood that these incidents will occur more frequently with climate change informs that the loads of their constituents may increase. Reduction in lakes levels owing to low rainfall and increased evaporation will reduce the relative dilution of those constituents and consequently, making their impacts on the lake ecosystems greater.

Bushfire are likely to be more severe and frequent under climate change. Ashes and other organic loads are likely to be washed into lakes that are situated in forested catchments. This will favour turbidity, nutrient enhancement with boom burst algal growth, reduced oxygen levels and formation of sediments. More consequential to the lakes is severe loss of water in a bid for the burnt forests to recover. Recovering forests draw considerably more water from the soil than a mature forest. This may probably decrease the quantity of water that flow into the lakes compared to the inputs from old-growth forests.

Floodplain lakes situated in low-lying areas are predominantly prone to sea-level increases. Besides the risk of direct input of sea water to such lakes, during high tides, there is likelihood of groundwater intrusion which may result in increase salinity. The intrusion of sea water will have stern impact on the ecology and efficiency of the affected lakes. This include the toxic effect of increase in the salt content and the consequential loss of maccrophytes that serve as natural habitat to macro invertebrates, zooplankton and benthos leaving them more exposed to predators. In serious cases, saltwater intrusion could lead to collapse of the freshwater ecosystems.

5.4. Climate Change and Fish Productivity, Breeding and Survival

Though, high temperatures may positively affect fish farming by boosting productivity and encouraging fish farmers to breed new varieties, impending challenge may arise from the fact that pathogens survive more in warmer water. Walter *et al*. (2002) suggested that different species of fish respond differently and in varying degrees to climate change. This makes it impossible to identify general ways in which fish populations can respond to climate change, because the number of influential factors is too large (Lehodey *et al*., 2006). Changes in wind velocity and direction influence mixing of air-water interface and water circulation in the open floodplain lakes. It can also affect the vigor of upwelling within coastal ridges.

Fish have complex life cycles which comprises a number of definite life stages (egg, larva, juvenile and adult), each of which may be affected in different ways by climate change. Each successive life stages seem to require progressive separate habitats (Rothschild, 1986). It is very important however, that in order to maintain a persistent population, connectivity among the habitants necessary for successive life stages must be guaranteed. This will help the organism to mature and go back to the spawning ground to produce offspring successfully. However, Ishimatu *et al*. (2005) opined that manipulation of pH and CO_2 can have remarkable consequences on the physiology, metabolism and reproduction biology of fish more especially in egg fertilization and survival of early developmental phases.

Changes temperature and oxygen content in water can force organisms to respond to a point of changing its behavior al pattern. Meanwhile, the responses will be dependent on the capacity of the organism to perceive the gradient and traverse accordingly. In contrast to early feeding larvae of tropical floodplain lake fish, which can have strong swimming capacity, larvae of most temperate marine fish species have no, or very limited, swimming ability (Leis, 2006). Ordinarily, some individuals that even possess strong swimming capacity lack perfect knowledge of the location of optional habitats. Productivity of fish populations, in terms of density,

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is determined by recruitment, growth and death rates. Relatively small changes in growth and death rates during the egg and larval phases can have a large consequence on the recruitment success of the fish population. Productivity will also be subjective to the effect of temperature on growth rate (Brander, 1995; Teal *et al*., 2009).

At sexual maturity, fish species generally appear plastic in their age and size. Increase in temperature results in increase in juvenile growth and consequently, leads to decrease in the length or age of first maturation, which will affect the growth of adults being that, a lot of energy may be channeled into reproduction at an earlier age (Heino *et al*., 2002). When temperature is extremely high, it can also lead to high mortality. Consequently, to predict climate change effect on floodplain lakes ecosystem, and the output and biomass of different fish species, especially in light of the further pressure of exploitation, will be a striking challenge for the future (Green and Pershing, 2007), hence, the need for ecosystem based management.

5.5. Impacts of Climate Change on Floodplain Lake Birds and Mammals

Birds, mammals and fish and invertebrates species can really point to us the impact of climate change on the ecology of the tropical floodplain lake. Floodplain lakes are diverse and complex and its ecosystem may not easily be studied. Birds, mammals and their food sources are all facing challenges brought about by changing climate that have already affected naturally existing water conditions such as upwelling, surface temperature and other events. These water conditions influence the availability, quantity and location of prey. When there is no enough prey for water birds or predating mammals, it affects their chances of survival and reproductive rate. Consequently, the reproduction and survival of water birds and mammals may be affected by climate change as it can modify their breeding time and distribution. Good upwelling with low surface temperature in the lake is required for water birds to have enough prey in the floodplain lakes.

Climate can also change the sex ratio of a population. The number of males and females can be influence by the change in climate. This is because these conditions can either reduce or disperse food sources for either the male or female counterparts being that, males and females feed on different food resources. Anthropogenic global warming is predicted to reduce ocean productivity, increase dietary stress on female, and an overproduction of males that may adversely affect all regulated floodplain lake populations.

5.6. Climate Change and the fishing Communities.

Obviously, changing climate patterns, rising temperatures and more acidic water bodies (lakes, oceans and rivers) is an indication that global warming has made substantial impacts on people across the world. On the local sense, many communities dependent on natural resources are seeing the effect of climate change to be a big threat to their means of livelihood. For example, in the riverine communities, islands and along the floodplains, fishing is their major source of livelihood; serving as source of income and providing them with protein and other stable nutrients. This is almost now impossible and being compounded by increased water temperatures which have significantly killed greater percent of the common species in the tropics. Most remarkably, there is an explicit lack of juveniles for many vital fisheries species, which makes tomorrow's catch look on the brink.

Modestly speaking, rising water temperature of Floodplain Lakes and the like of ocean acidification are radically changing aquatic ecosystems. This modifies the distribution and productivity of fish species in the lakes. The fishing communities along the floodplains who depend on fish stocks for livelihood will be mostly affected by change in climate - with change in the patterns of rainfall and the associated flooding more likely. The coastal fishing communities along the tropical floodplain depend solely on fishing and are now seriously affected by the impacts of climate change. Low-lying communities may become the first climate change refuges. Fishing communities in Bangladesh for example, are subject not only to water -level rise, but also to flooding and increased typhoons. Fishing communities along Mekong River floodplain produce over one million tons balsa fish yearly. Salt water intrusion as a result of rising sea level and dams poses greatest challenge to fish production. Fish and aquaculture provides a significant food security. Aquaculture is the world's fastest growing food production system, growing at 7% annually and fish products are among the most extensively traded food. The spate of flooding in tropical floodplains and loss of juveniles of fish species is a threat to the fishing communities and a concern to the world economy.

6. ADAPTATION, MITIGATION AND INTERVENTION

Some of the measures that could be taken to mitigate the impact of climate change on the tropical floodplain lakes include:

- **Plant Buffers:** Planting of riparian buffers with a local watershed group will be good intervention measure to mitigate the impact of climate change on the floodplain lakes. The roots of the buffer plants will hold the soil in place and protect habitat and water quality downstream.

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- **Defend against Invaders:** This measure entails planting native plants that will compete with invasive for habitat. This will continue to enhance the water condition.
- **Dump no Bait in the lake:** Leftover baits should be disposed of in trash receptacles away from the water bodies. This will help to maintain sanity and good water condition in the lake.
- **Get More pervious:** Minimize impervious surfaces like drive ways, sidewalks and roofs around the floodplain lakes.
- **Catch the Drip:** Rain barrels are to be installed to help catch the roof runoff … then water the flow garden.

6.1. Harnessing Opportunities Brought by Climate Change

There are many literatures that extensively discussed some negative impacts of climate change. However, there are overwhelming positive impacts and variability on some areas and on fisheries in particular that are not dully pointed out in those literatures. Climate change impacts can never be distributed equally. There will surely be relative "winners" and "losers". While some communities may suffer significant losses due to physical damages or changes in fish distribution, others will be less affected and/or may even benefit. For example, rise in temperature can lead to early maturity of certain species and consequently leads to increase in its abundance. Successful identification of polices that enhances adaptation will only occur if the opportunities brought by climate change are taken into cognizance.

7. CONCLUSION

The study of tropical floodplain lakes will be essential if tropical inland waters are to be protected and used in the wisest possible ways. Though, it may not practically be feasible to protect all the tropical floodplain lakes, it will be necessary for policy makers and stakeholders to formulate intervention strategies in order to protect most vulnerable ones especially, those that are associated with climate change. In order to ensure that the healthy status of tropical floodplain lakes are being kept, there is need to focus on maintaining their hydrological connection with water feeder sources and reducing the amount of water diverted from the lakes. Prioritizing lakes that are of high environmental, social and economic value and/or representatives of a certain class of lakes will be important, since not all lakes may be able to be protected in their current state. Community engagement in establishing priorities and management responses will be important to protect tropical floodplain lakes.

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Conflicts of interests

The authors declare that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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