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POLICY BRIEFS

# Satellite Earth Observation for the Sustainable Management of the African Great Lakes

**AUTHORS:** **Emma Tebbs,** King's Water Centre, Department of Geography, King's College London
**Aidan Byrne,** King's College London
**Davide Lomeo,** King's College London
**Henry Thompson,** King's College London
**Winnie Owoko,** Kenya Marine and Fisheries Research Institute (KMFRI)
**James Nyaga,** Regional Centre for the Mapping of Resources for Development (RCMRD)
**Collins Ongore,** Kenya Marine and Fisheries Research Institute (KMFRI)
**James Last,** Kenya Marine and Fisheries Research Institute (KMFRI)
**Zeph Migeni,** African Center for Aquatic Research and Education (ACARE)
**Lucy Everitt,** King's College London


**Figure 1:** *Kenyan fishers at work on the shores of the Lake Victoria*

## KEY MESSAGE

The African Great Lakes support rich fisheries and biodiversity, and a rapidly growing population; however, they are under threat from a range of anthropogenic pressures such as climate change and pollution. A lack of consistent monitoring data prevents adaptation and management; there is a critical need for a satellite-based monitoring system to underpin science and decision-making. King's College London has teamed up with local partners to co-develop solutions, including the Kenya Marine and Fisheries Research Institute (KMFRI), the African Center for Aquatic Research and Education (ACARE) and the Regional Centre for Mapping of Resources for Development (RCMRD). We aim to use cutting-edge satellite technology to co-develop a system that will enable resource managers to investigate impacts of climate and human action on these lakes, informing policy and management for improved water quality outcomes for local communities and ecosystems.

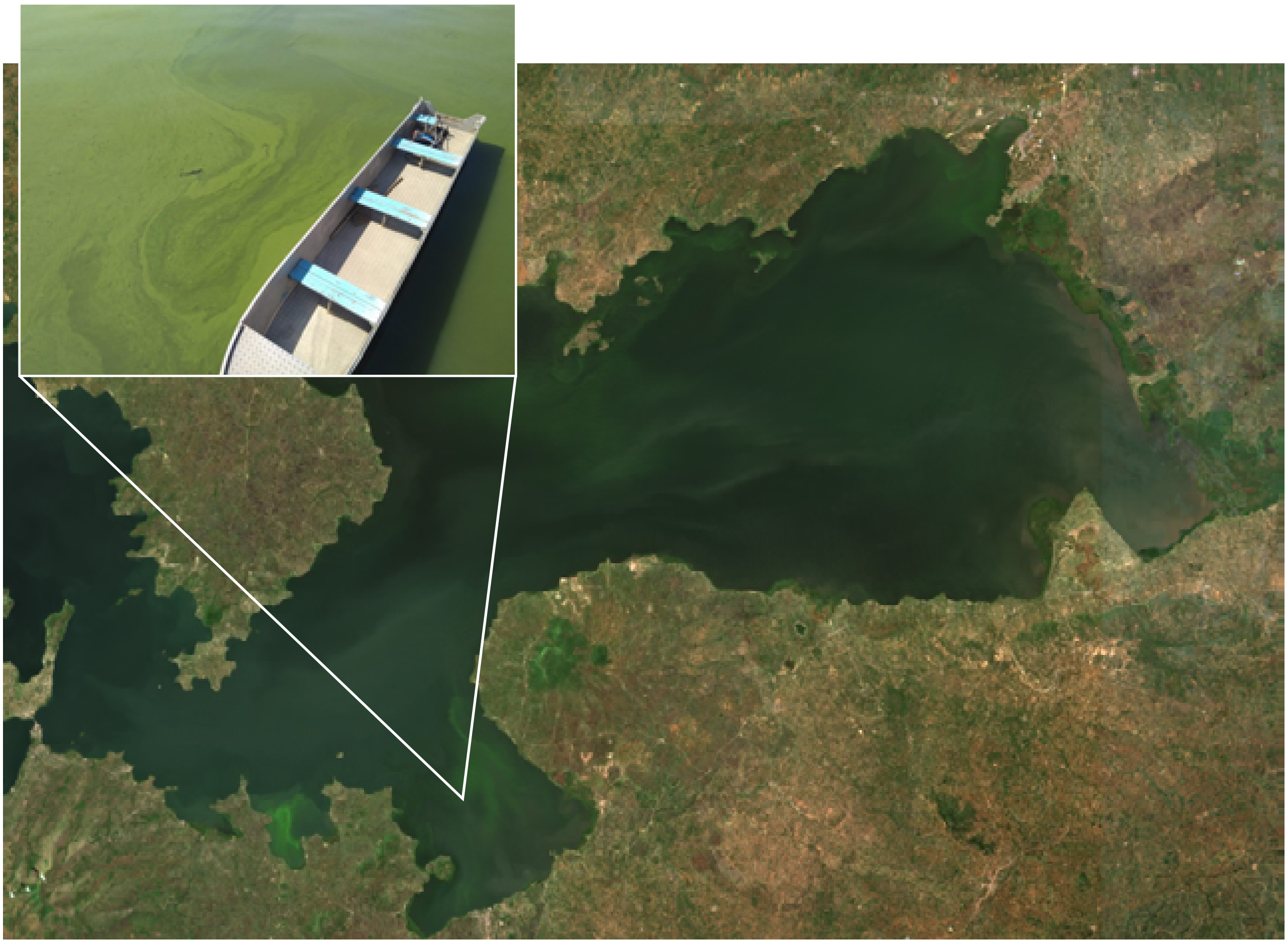
**Figure 2:** *Location of the African Great Lakes.*


## LAKES UNDER THREAT

Accounting for 85% of the world's surface freshwater, lakes are critical for global water security and freshwater biodiversity. However, they are highly vulnerable to anthropogenic disturbance.[1] This is particularly true of the African Great Lakes (Figure 2), which support the livelihoods and food security of >90 million people.[2] Despite being home to ~2,000 endemic fish species[3] and representing a major source of prosperity in the region, the health of these ecosystems is threatened by climate change, eutrophication, invasive species and emerging threats such as rapidly expanding cage aquaculture fisheries. Water quality is deteriorating and harmful algal blooms are becoming more frequent,[4] but our understanding of what is driving these changes, and how to mitigate them, is limited (Figure 3).

To fully understand the driving factors and develop solutions in turn, we need consistent long-term observations. However, current monitoring efforts are sporadic and infrequent. Local institutions have scarce resources, and monitoring using traditional boat surveys is time consuming and costly. Recent rallying calls from experts have asserted the need for harmonized long-term, multi-lake monitoring for the African Great Lakes to ensure their sustainable use;[5] cutting-edge satellite Earth Observation (EO) technologies represent an opportunity to address this data gap.

**Figure 3:** *Sentinel-2 satellite image of Winam Gulf, Lake Victoria, Kenya, showing the location of a microcystis bloom observed in June 2022*



## HOW SATELLITE OBSERVATIONS CAN HELP

Satellites can provide frequent and continuous long-term observations over large spatial scales; as a result, satellite EO is more cost-effective than ground-based surveys. It can provide information on a wide range of parameters, including:

1. **Water quantity:** for example, water levels, surface-water extent and soil moisture
2. **Water quality:** for example, chlorophyll-α concentrations, suspended sediments and harmful algal blooms
3. **Climate:** for example, rainfall and temperature levels
4. **Catchment properties:** for example, land cover and topography
5. **Aquatic plants:** for example, invasive floating plants, such as water hyacinth

Satellite EO data can be used to investigate how and why inland waters are changing as well as potential impacts for people and wildlife, thus allowing the impact of management interventions to be assessed. Providing powerful imagery and data for advocacy or integration into prediction models for analysing future impacts, it is widely accepted that satellite EO plays an important role in monitoring and delivering progress towards the UN Sustainable Development Goals.[6] By monitoring phytoplankton and invasive floating plants among other applications, there is huge potential to improve the management of the African Great Lakes and contribute towards regional sustainable development (Figure 4). For example, satellite EO could be used to evaluate the impact of cage aquaculture on water quality, providing the evidence needed to regulate this rapidly developing industry.

**Figure 4:** *Satellite monitoring of the African Great Lakes will contribute toward the UN Sustainable Development Goals, particularly goals 6, 13, 15.*

## MONITORING PHYTOPLANKTON

One avenue of satellite monitoring for improved lake management is the detection of sunlight reflected from waterbodies, which can tell us about the water's properties based on colour spectra. It can be used to analyse phytoplankton levels, for example – microscopic organisms inhabiting upper sunlit layers of waterbodies, forming the base of aquatic food webs. Satellites are sensitive to chlorophyll-α (a green pigment in plants, algae and cyanobacteria), which can be used as an indicator of phytoplankton concentration/biomass, providing information about the productivity of the ecosystem.

Too much phytoplankton can be a problem, however. Often induced by nutrient fluxes, near-monospecific assemblages can persist for months,[7] resulting in harmful algal blooms that can cause fish kills and ecosystem degradation.[8] Some blooms also release toxins that pose serious health risks to humans. Satellite data can be used monitor the spatial patterns, seasonal cycles and long-term trends in phytoplankton concentrations and harmful algal blooms, providing vital data for assessing potential impacts on people and developing mitigation strategies.

## MONITORING INVASIVE AQUATIC PLANTS

Satellite EO can also detect floating invasive aquatic plants, which represent a growing threat to life. Water hyacinth is one such species that is increasingly present in African lakes, destabilising ecosystems and costing the global economy US$ 21 billion.[9] Invading tropical aquatic ecosystems, its rapid growth can lead to clogged waterways, deoxygenation and provision of habitats for disease vectors, such as mosquitos. In Lake Victoria (bordering Kenya, Uganda and Tanzania), mats of the invasive plant have created localized 'dead-zones', affecting local wildlife and livelihoods.[10] Due to their free-floating nature and rapid growth rates, water hyacinth mats' spatial distribution across large lakes changes rapidly; managers require frequent, up-to-date maps to target control measures effectively. Water hyacinth has primarily been mapped in the African Great Lakes using optical satellite sensors, such as Landsat and Sentinel-2[11]; however, they are impacted by missing data due to cloud cover, limiting observation frequencies. There is potential to overcome this by integrating optical data with radar data, such as from the European Space Agency's Sentinel-1 satellite.[12]

## AFRICAN LAKES AND KING'S COLLEGE LONDON

At King's, researchers have developed methods for using satellite data to monitor phytoplankton concentrations (in Lake Bogoria) and classify lakes into different ecological states (for soda lakes in the Great Rift Valley, such as Lake Nakuru).[13,14] Additionally, Tebbs et al.[15,16] have so far used satellite remote sensing to reveal the effects of hydropower dams on hydrology and chlorophyll-α levels in Lake Turkana, and map highly dynamic floating plant invasions in Lake Victoria.

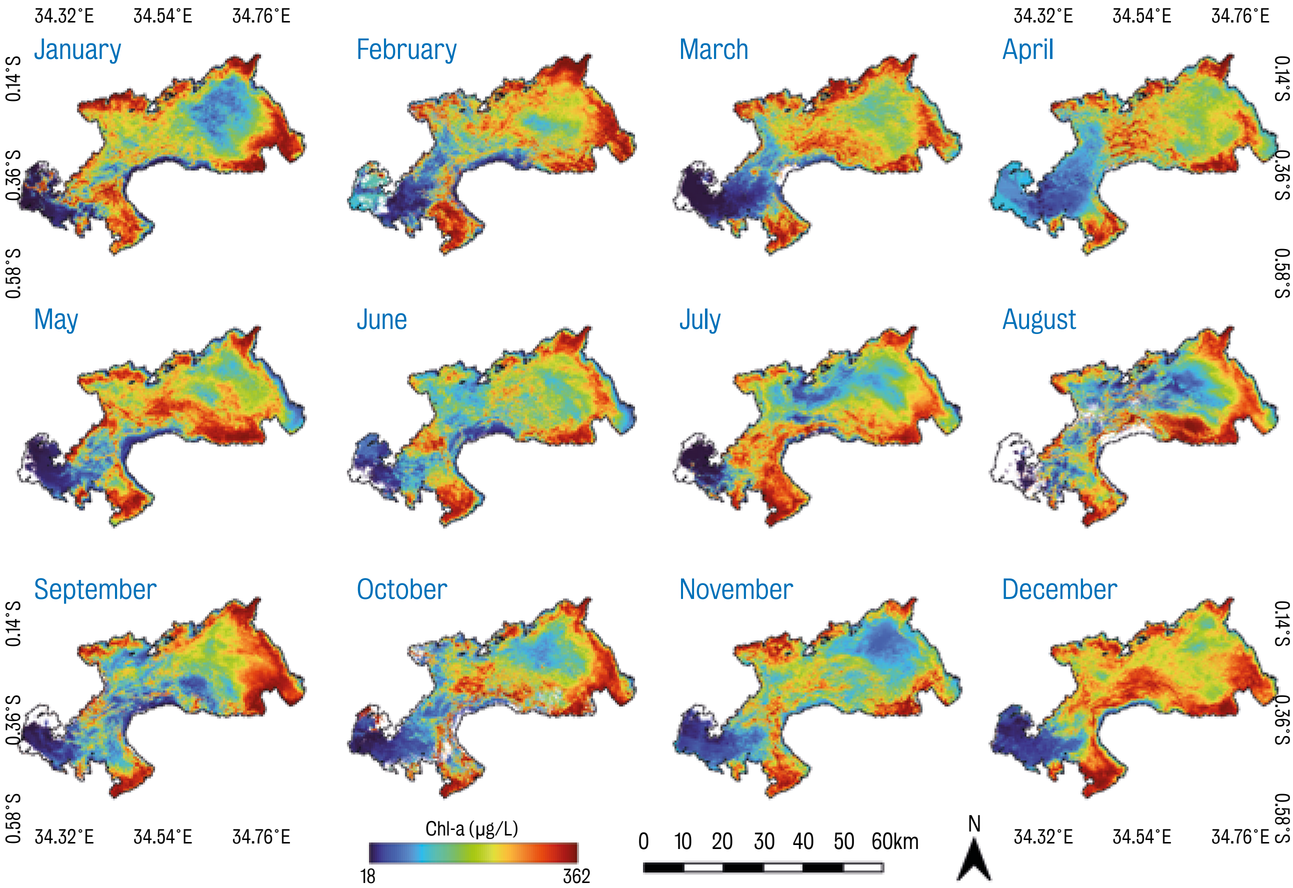
In June 2022, a workshop in Kisumu, Kenya (co-hosted by King's, KMFRI and RCMRD) identified enormous potential for satellite EO to contribute systematic data to improve the monitoring and management of African lakes. Local institutions expressed their eagerness to harness this potential to address the pressing challenges they face, and receive the vital training necessary for the project's success.

## BARRIERS TO IMPLEMENTING A SATELLITE MONITORING SYSTEM

In Lake Victoria's catchment, local stakeholders KMFRI, ACARE and RCMRD have identified, among others, fisheries and aquaculture management, harmful algal blooms and invasive floating plants as key priorities for tackling sustainability problems. All mandate for capacity building in EO technologies to meet their goals; however, current methods are site-specific and not easily transferable.

Available global satellite products have been developed using data primarily from North American and European waterbodies, and their reliability for African lakes is uncertain.[17] There is a need for satellite EO algorithms to be tailored to local conditions, but this requires 'ground-truth' observations to calibrate the satellite algorithms and assess their accuracy. While local institutions recognise the huge potential, they lack the capacity to collect ground-truth data and skills required to take full advantage of satellite EO's opportunities.

**Figure 5:** *Chlorophyll-α maps for Wiman Gulf, Lake Victoria, Kenya, derived from Sentinel-2 imagery. Monthly averages for the period 2016–2022.*




## OUR SOLUTION

At King's, we propose working with local partners to develop a satellite-based monitoring system for the African Great Lakes, which will provide vital data to underpin science and decision-making. We will use a 'Living Labs' approach, working closely with local scientists and water managers to co-create solutions and ensure our system meets the needs of stakeholders across the region. Delivering a satellite-based monitoring system for the African Great Lakes will require:

1. Developing local institutions' capacity to collect data for 'ground-truthing' satellite observations;
2. co-creating accurate satellite products with local partners, tuned to local conditions;
3. producing open-source and user-friendly software tools for visualising and analysing data; and
4. providing training to local researchers and managers.

## WORK SO FAR AT LAKE VICTORIA

During co-design with local partners, Lake Victoria, the world's largest tropical lake, was identified as a system with high potential for satellite EO to contribute to science and management. Supporting the livelihoods of ~40 million people,[18] solutions developed to tackle Lake Victoria's water problems have the potential to benefit a large population growing at one of the highest rates globally.[19]

So far, we have conducted fieldwork in Winam Gulf (also known as Nyanza, or Kavirondo Gulf, in June 2022), Lake Victoria, and combined collected 'ground-truth' data with satellite data. At 26 stations, water quality parameters and hyperspectral reflectance measurements were collected in collaboration with researchers from Bowling Green State University, USA, University of Windsor, Canada, and Kisii University, Kenya; this data was then used to evaluate the performance of various satellite sensors and determine the best algorithms for measuring chlorophyll-α levels. Maps depicting the spatial and temporal patterns of chlorophyll-α in Winam Gulf were then created (Figure 5).

## LOOKING FORWARD

At King's, we are collaborating with Cornell University and KMFRI to investigate harmful algal blooms in Lake Victoria using our satellite-based monitoring tools.[20] We want to link our chlorophyll-α data with climate, land-use and socio-economic information to understand:

1. What is driving harmful algal blooms in the lake; and
2. potential health impacts for local communities from toxins associated with some of these blooms.

To continue this vital work, we need additional funding for the installation of automated sensors for 'ground-truthing', co-development of satellite products and production of our web portal for accessing the data.

Once developed, our monitoring system will enhance the science and management of African lakes by allowing managers to better monitor the impacts of climate change and other human activities. This will provide vital evidence to inform policy and management decision-making, ultimately leading to cleaner waters, healthier ecosystems, and improved health outcomes and livelihoods for local communities.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## CONTACT


Dr. Emma Tebbs (emma.tebbs@kcl.ac.uk),
King's College London


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## HOW TO CITE THIS WORK


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