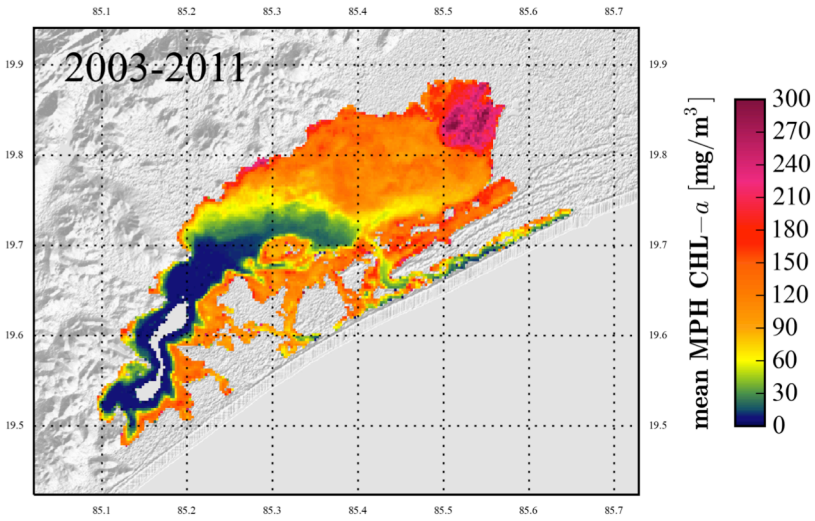
Tools from Earth Observation for Lake Management in Emerging Countries

Developing countries around the world are particularly vulnerable to deteriorating water quality, due to intensive agricultural practices, high population numbers, and often-poor sanitation. This leads to an increase in pollutants, in particular nitrates and phosphates from agriculture and fertilizer, entering water supplies, stimulating the proliferation of aquatic weeds, algal blooms and harmful cyanobacteria (also known as blue green algae). Developed countries often have the opportunity to implement mitigation strategies to avoid environmental disaster; including improving sanitation and enforcing improved agricultural practices. However, in many developing nations, including those featured here, the means and will to prevent such disasters are often lacking. In this story, we showcase several examples where Earth observation technology may be used to monitor and assist mitigation of environmental disasters from eutrophication, infestation of invasive aquatic weed, and severe toxic cyanobacteria blooms, which affect lakes in developing countries. The examples show products derived from the Maximum Peak Height algorithm (Matthews and Odermatt, 2015), which is designed for use with operational systems observing the world's lakes.

Eutrophication of Chilika Lake (India)

Chilika Lake, in Odisha State on the East Coast of India, is the second largest lagoon in the world at 1100 km^2, connected to the Bay of Bengal. As a wetland of international significance under the RAMSAR convention, the lagoon supports a large number of subsistence fisherman, and is of high importance for breeding of migratory birds, and ecological diversity.

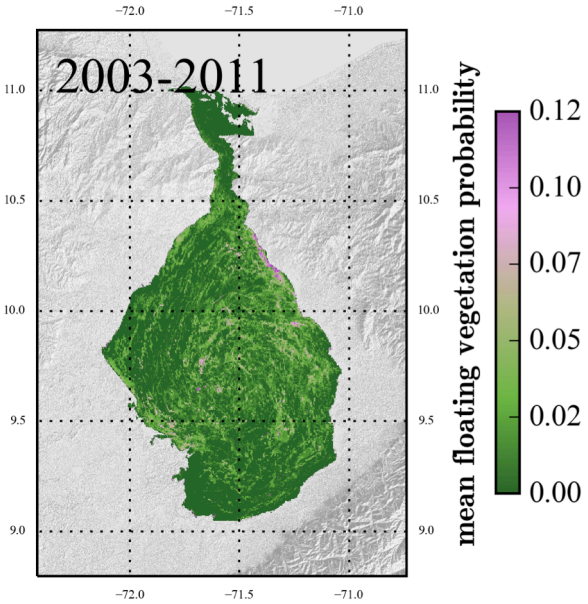


Ten year average chlorophyll-a concentration, Chilka Lake.

From the time series of satellite observations combining 9 years of data acquired between 2003 and 2011 there is evidence of high levels of eutrophication in the northeastern region of the lagoon with chlorophyll-a concentrations exceeding 200 µg L^{-1}. This is driven by high input of nutrients from many rivers that enter the system in this region (Costanzo et al., 2012). There is considerably improved water quality in terms of eutrophication southwestern region of the lagoon, which from an ecological diversity perspective is encouraging. However, the substantial hyper-eutrophication of most of the area of the lagoon, concentrated in the northwestern corner, is cause for concern. It calls for action in order to ensure the ecological integrity of large regions of the Lagoon is not compromised in the future.

Invasive duckweed infestations in Lake Maracaibo (Venezuela)

Lake Maracaibo is located on the Gulf of Venezuela in South America, and is the largest lake in South America, covering an area of approximately 13 000 km^2. It is connected to the sea via the Tablazo Strait in the north and is fed by the Catatumbo River. The region is economically important for oil production and supports large numbers of subsistence fisherman



Floating vegetation probability for 10 years of satellite data for Lake Maracaibo, indicating the infestation of duckweed.

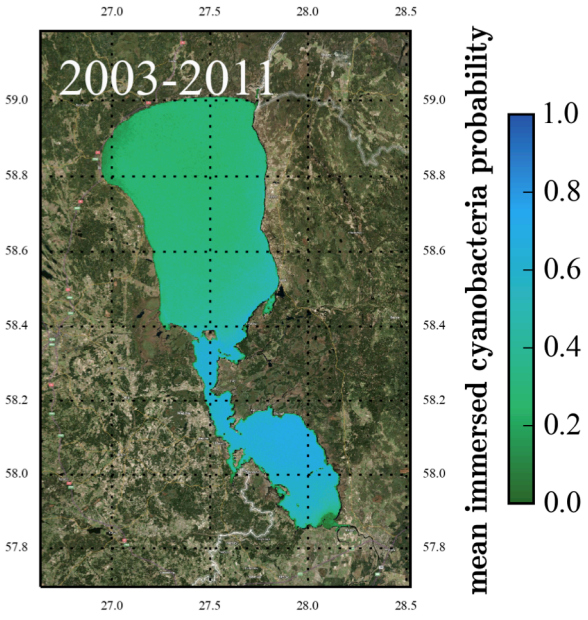
and villagers who live in houses built on stilts on the lake (Hoag, 2000). The lake has recently become infested by duckweed *Lemnoideae*, an invasive plant that floats on the water surface. The plant has covered huge areas of the lake. High levels of dissolved nutrients originating from effluent and agricultural sources drive the proliferation of duckweed. It has a negative impact on fisheries because it clogs the engines of boats, and also on biodiversity though shading other sensitive plant species, as well as encouraging bacterial activity such as cholera. Mechanical removal of the plant is the only remedy, and has cost the Venezuelan government millions of dollars per annum.

Using satellite observations, it is clear that duckweed still infests large areas of Lake Maracaibo, and represents an ongoing challenge for water management in Venezuela. The swirling patterns of duckweed on the lake surface show an unusual cyclonic circulation. The duckweed infestation is likely to be a symptom of an underlying environmental disaster: raw effluent, industrial waste and agricultural waste continue to flow into the Lake. The use of satellite products will assist mitigation measures into the future.

Cyanobacteria blooms in Lake Peipus (Russia and Estonia)

Lake Peipus (or Peipsi) is a large freshwater lake situated between Estonia to the west and Russia to the east. It has a surface area of 3555 km^2 and is the fifth largest lake in Europe. The lake is frozen between December and April, but warms up in the summer with water temperatures above 20°C. The warmer temperatures stimulate cyanobacteria blooms (blue green algae), which thrive on high concentrations of nutrients originating from agriculture. Some of the cyanobacteria species are associated with the production of toxins, which may be harmful to humans and animals if ingested in large quantities. Poisonings of livestock and wild animals are a frequent occurrence with the kinds of cyanobacteria present in Lake Peipus (Laugaste et al., 2013). The cyanobacteria blooms therefore represent a threat to health for recreational, agricultural and potable users.

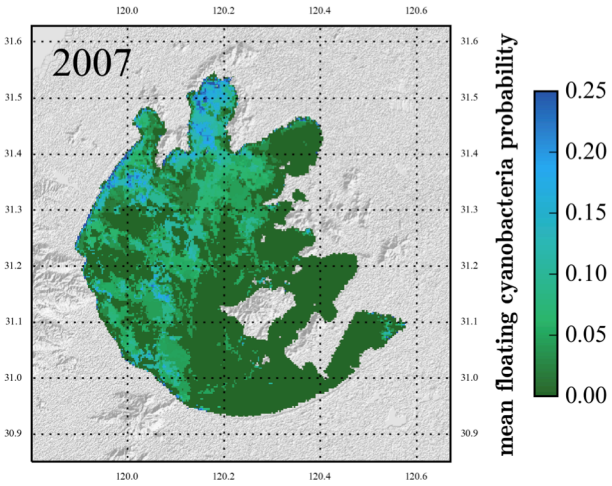
Satellite observations are a useful tool for quantifying the risk associated with cyanobacteria blooms, and for public information services issuing health warnings to the general public. They show that the highest probability and occurrence of cyanobacteria blooms is in the southern basin, known as Lake Pihkva, and the sound connecting the northern basin. This information, accompanied by near real time information, may be used to support lake management policies and mitigation efforts.



Probability of cyanobacteria blooms derived from satellite for Lake Peipus.

Cyanobacteria surface scum, Lake Taihu, China

Cyanobacteria have a tendency to accumulate in extremely high density by floating on the water surface. In such cases, they form mats or scum on the water surface. Cyanobacteria surface scum represent a significant health threat, and pose a high risk for the production and occurrence of cyanobacteria toxins. They are also a considerable menace for water treatment, are aesthetically displeasing, and exude an unpleasant odour. Lake Taihu in China has been severely affected by cyanobacteria blooms and scums in recent years, which in 2007 famously drove up the price of bottled water (Associated Press, 2007). In the case of cyanobacteria scums authorities are responsible to issue health warnings. However this is often not feasible given a lack of sufficient monitoring capacity.



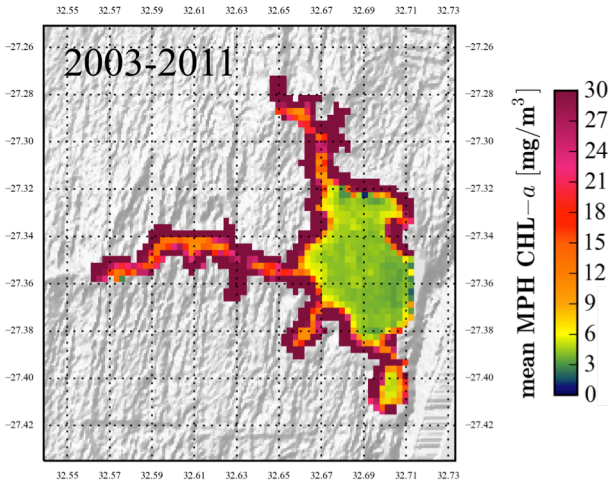
Probability of cyanobacteria scum on Lake Taihu in 2007. Near real-time products may be used to issue health warnings.

Satellite data are a reliable source of near real time information, which can help prevent unwanted exposure to cyanobacteria. Newly developed products have enabled the identification of cyanobacteria surface scum events. This will in future enable authorities to issue timely warning on the whereabouts and intensity of cyanobacteria blooms minimising negative health impacts.

Threats to a pristine coastal lake, Lake Sibhayi, South Africa

South Africa is a water stressed country, with a scarcity of natural lakes. Lake Sibhayi, situated on the southeastern coast in the Kwazulu Natal province, is a small coastal lake, with an area of just 55 km^2. Despite its small size, it is the largest fresh standing water body in South Africa, and is therefore a critical site for the diversity and conservation of freshwater fishes and avifauna. This is recognised by its inclusion in the Greater St. Lucia Wetland Park, which is a UNESCO World Heritage Site. Lake Sibhayi is therefore important for conservation, tourism and recreation, and is used as a potable water source for various water supply schemes in the region. The preservation of its ecological integrity is therefore of very high priority. Studies from the 1970s found that the Lake was in pristine condition, with exceptional water clarity, low concentrations of algae, with chlorophyll concentration below 4 µg L^{-1}, and abundance of fish species (Allanson, 1979). Through analysis of satellite data collected over the last decade, we can assess whether these conditions remain so today.

Satellite observations indicate that whilst the lake is by comparison to other highly impacted systems, in pristine condition, there is evidence of an increase in algal biomass up to 10 µg L^{-1} resulting from input of nutrients (Figure 5). Whilst there appears from the data to be no cause for immediate concern, the situation requires careful and on-going assessment by authorities in



Ten year average Chlorophyll concentration for a small coastal lake Sibhayi, South Africa (2002 to 2012). Note that the high values near the shoreline are from clear shallow water and not algal blooms.

order to ensure the pristine conditions continue to prevail in this sensitive system. This example demonstrates that satellite monitoring is an ideal tool to monitor small changes occurring even in small systems such as Sibhayi.

Summary

The above examples demonstrate the severity of environmental problems affecting lakes in developing countries, and the considerable benefit that satellite earth observation can offer for routine monitoring and assessment. It points towards a future in which information services based on satellite earth observation are used to inform management decisions, enhance mitigations measures, issue public warnings and improve human health. Utilising innovative tools from earth observation in lake management will avoid environmental disasters and enhance the conservation of the world's precious lake environments.

Further reading

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Laugaste, R., Panksep, K., and Haldna, M. (2013). Dominant cyanobacterial genera in Lake Peipsi (Estonia/Russia): effect of weather and nutrients in summer months. Est. J. Ecol. *62*, 229–243.

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