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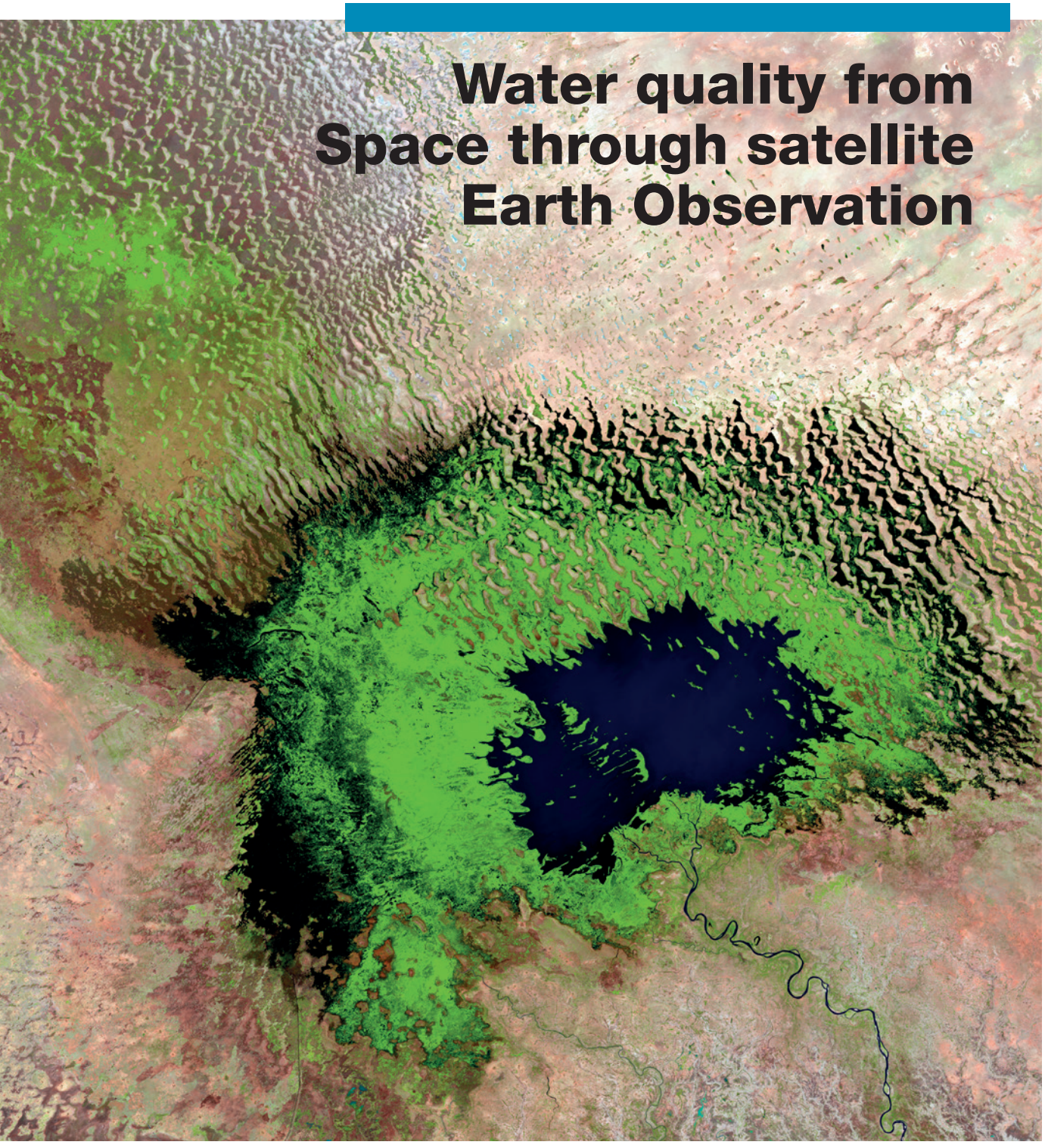
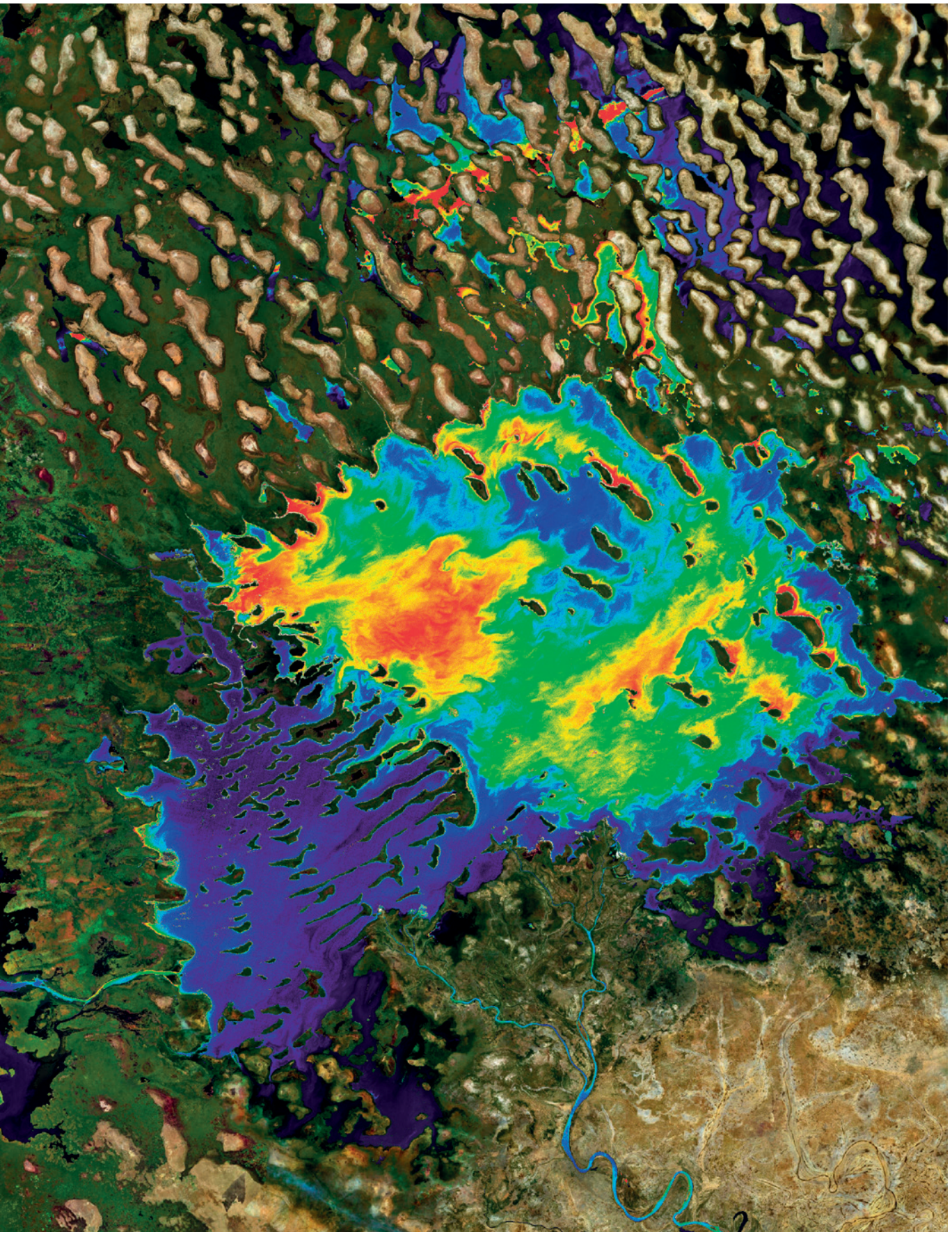
UNESCO World Water Quality Portal

Water quality from Space through satellite Earth Observation





UNESCO World Water Quality Portal

Clean water and healthy ecosystems are vital for sustainable development and human well-being. However, water quality in world's freshwater resources is declining. Water quality monitoring is fundamental to ensuring safe water for all and protecting the ecosystem health and diversity. Yet, data and information on water quality are scarce globally, especially in remote areas and in countries, where water quality monitoring networks and capacities are lacking. The use of satellite Earth Observation (EO) and remote sensing technologies in freshwater quality monitoring has immense potential to enhance water quality data at the global, regional, national and basin scales.

The UNESCO World Water Quality Portal is an innovative tool for freshwater quality monitoring through satellite EO, combined with field measurements. Using EO satellite images, the portal enables water quality monitoring in surface water bodies even in areas without monitoring networks. The portal provides EO satellite-derived data on key water quality indicators: temperature, turbidity, suspended matters – (chlorophyll-a), harmful algal blooms (HAB) and dissolved organic matter. Other measurements such as water surface area and water level are also monitored through EO satellites. These data are indispensable for better understanding water quality and the ecological state of water resources, monitoring the trend and evolution of water quality and pollution over time, identifying pollution hotspots, and assessing anthropogenic and climate change impacts on freshwater ecosystems.

The principal aim of the portal is to promote innovative approaches to freshwater quality monitoring and enhance water quality data at the basin, national, regional and global levels. The portal furthermore aims to support governments, national water agencies and basin organizations in improving water quality monitoring and enhancing their capacities to manage water resources in a sustainable way. It provides the basis for the development of water management strategies, policies and decision-making based on sound scientific data and evidence.

The water quality data provided by the portal support for the national implementation of the UN 2030 Agenda for Sustainable Development Goals (SDGs)—in particular, monitoring and reporting of the SDG 6 on "Clean Water and Sanitation for All" and its Target 6.3 on improving water quality and reducing water pollution, and Target 6.6 on protecting and restoring water-related ecosystems.

Data sharing is imperative for transboundary water cooperation between riparian countries. The portal supports peaceful and sustainable management of transboundary water resources by providing an innovative tool for water quality monitoring and data sharing in transboundary basins.

By facilitating access to and sharing of open data on water quality for different stakeholders, the portal contributes to open science and awareness raising on water quality of the public at large within and beyond basin boundaries.

The concept of the UNESCO World Water Quality Portal was developed in the framework of the International Initiative on Water Quality (IIWQ) of the Intergovernmental Hydrological Programme (IHP) of UNESCO.

DEMONSTRATION PHASE

The demonstration phase of the UNESCO World Water Quality Portal was implemented in 2015-2018 to showcase the potential application of satellite EO to freshwater quality monitoring. The demonstration portal provided non-calibrated satellite-derived water quality data at a 90-meter spatial resolution at the global level for the year of 2016. It also provided higher 30-meter resolution time series data on water quality in selected river basins in world's different regions, including: Lake Sevan in the Caucasus highlands in Armenia and Azerbaijan; the Itaipu Reservoir and Parana River Basin, shared by Argentina, Brazil and Paraguay; the Mecklenburg Lake Plateau in Germany; the River Nile and Aswan Reservoir, Egypt and Sudan; the Mekong Delta in Vietnam; the Florida Lakes in USA; and the Zambezi River Basin in Zambia and Zimbabwe.

THE SCIENTIFIC APPROACH: THE USE OF SATELLITE EARTH OBSERVATION

UNESCO promotes the advancement of science and innovation for peace and sustainable development.

The UNESCO World Water Quality Portal builds on innovation in environmental remote sensing and satellite technologies, which has huge potential to improve freshwater quality data globally.

The scientific approach used in the UNESCO World Water Quality Portal is characterized by monitoring water quality through spectral information of the reflectance of water surface captured by EO satellite images. Water surface reflectance indicates the presence of optically-active components in a surface water body such as the presence of certain pollutants in lakes and rivers. Suspended solids, photosynthetic pigments and organic matter in a water body alter the colour of the water and thereby affect the reflectance of the water surface. Accordingly, these components present distinct spectral signatures on the reflectance of the water surface in the visible, near infrared and thermal infrared spectral regions. As a result, a quantitative assessment of some water quality indicators can be interpreted from EO satellite images. The spectral reflectance of the water surface captured by EO satellite images is modelled into values of different water quality indicators by computational algorithms. Water quality data from EO satellite images on the UNESCO World Water Quality Portal are generated by open-source algorithms[1].

1. The UNESCO World Water Quality Portal uses open-source algorithms, developed by the French Space Agency (CNES) and French National Research Institute for Sustainable Development (IRD).

Water quality data processing chain for EO satellite images

SATELLITE IMAGES
Sentinel-2 and Landsat satellite data

ATMOSPHERIC CORRECTIONS
Atmospheric and sunglint correction using GRS module

WATER DETECTION
Automatic water detection using machine learning techniques with Water Detect module

SIGNAL INVERSION
Retrieving water quality parameters using radiometric algorithms

MAPPING
Application of all previous algorithms on satellite images and production of water quality maps

SCIENTIFIC VALIDATION OF SATELLITE-DERIVED DATA THROUGH *IN-SITU* MEASUREMENTS

Scientific validation and data calibration constitute an important and integral component of the use of EO satellite data. The calibration and validation of satellite-derived data is necessary for ensuring the quality and reliability of data.

In order to underpin the scientific approach applied to the UNESCO World Water Quality Portal, satellite-derived water quality data are validated using field (*in-situ*) monitoring data and algorithms previously published in scientific peer-reviewed journals.

The *in-situ* monitoring data on water quality collected through field measurements are available on an open access basis on the Portal, along with their geolocation data.

ENVIRONMENTAL EARTH OBSERVATION SATELLITES

Advances in environmental EO satellites during the past decades have made possible the use of higher resolution satellite images for freshwater quality monitoring.

The UNESCO World Water Quality Portal uses open-source EO satellite images from:

- European Copernicus environmental satellite Sentinel-2 of the European Space Agency (ESA), and
- Landsat 8 and 9 satellites of the United States Geological Survey (USGS) and National Aeronautics and Space Administration (NASA).

Sentinel-2 Earth Observation satellite of the European Space Agency

Freshwater quality monitoring through satellite Earth Observation

The UNESCO World Water Quality Portal provides EO satellite-derived and *in-situ* data for main water quality indicators that determine the ecological state of a water body, including: turbidity, suspended particulate matter, chlorophyll-a, cyanobacteria and Harmful Algal Blooms, dissolved organic matters, and water surface temperature. In addition to water quality data, the portal provides satellite-derived data on water surface area and water levels, allowing for the monitoring and assessment of climate change impacts such as effects of precipitation changes and global warming.

- **Suspended Particulate Matter** (also called "suspended solids") is an indicator of the total amount of organic or inorganic particulate matters suspended in the water column, which affect the transparency of water and the amount of sunlight available for photosynthesis of aquatic organisms. A high concentration of suspended solids results in a low transparency of the water. It is a key water quality parameter that indicates sediment transport in river systems and the intensity of erosion processes in the upstream watershed. Concentrations of suspended particulate matter in the water are expressed in mg/l.

- **Turbidity** is an optical characteristic of water, which indicates the degree to which light is scattered by organic or inorganic particles suspended in the water. A high turbidity often indicates low transparency of the water due to the presence of solids, sediments, or pollutants, often resulting in poor water quality. Turbidity measurement is one of the standard parameters of water quality monitoring programmes. For the portal, turbidity is measured in Formazin Nephelometric Units (FNU).

- **Dissolved Organic Matter** is an indicator of biogeochemical processes in ecosystems. It indicates an advanced stage of degradation of organic matters in aquatic or terrestrial ecosystems of a local watershed. Dissolved organic matter in the water may originate from plant litter, soil organic matter, or produced by soil microorganisms. The presence of dissolved organic substance in a water body controls light absorption and is measured using its light absorption coefficient in the wavelength of blue (440 nm). Satellite data allow monitoring the Coloured Dissolved Organic Matter (CDOM), which is a fraction of dissolved organic carbon present in the water column. It is expressed in a unit of m^{-1}.

- **Harmful Algal Blooms (HAB)** is an excessive growth of algae (known as "algal bloom") in a surface water body. Algal blooms affect water quality, ecosystem health, aquatic life and the availability and quality of water supplies for cities, agriculture and industries. The combination of increased nutrient levels and warmer water temperatures create favorable conditions for excessive growth of algae in a water body. An algal overgrowth is called a Harmful Algal Bloom (HAB) if it is produced by a harmful algae specie such as cyanobacteria (also known as blue-green algae), which release toxins that may harm people, animals and aquatic organisms. The proliferation of HABs is a major global concern due to oxygen depletion (hypoxia or anoxia) in inland surface waters and coastal estuaries. In addition to odour and aesthetic problems (green or red scums on the surface of water bodies), HABs can cause fish death and serious risks to the public health

and animals. Water quality monitoring programs often include HABs as their standard monitoring parameters. For the portal, the HAB measurement from satellite images was carried out using the Normalized Difference Chlorophyll Index.

- **Chlorophyll-a** is the most common photosynthetic pigment in plants. It is essential for photosynthesis in aquatic ecosystems. The level of chlorophyll-a indicates the trophic state of a surface water body and phytoplankton abundance and biomass in the water. It is a key water quality parameter. High chlorophyll-a levels may indicate poor water quality due to high nutrient loads, low dissolved oxygen, and aesthetic problems such as green scums and bad odours. Chlorophyll-a levels in the water are expressed in µg/l.

- **Surface water temperature** is a key parameter that determines the ecological state of lakes and affects water quality. Water temperature affects other water quality parameters, including: dissolved oxygen levels, chemical and biological processes (such as promoting algal blooms and bacteria growth), species diversity in aquatic ecosystems, water density and stratification. The portal provides satellite measurements of water surface temperature (°C), corresponding to the instantaneous temperature of the water at the top of the surface (a thin layer of 10-20 µm), called the "skin temperature".

- **Water surface variability:** The portal provides data on open water of a surface water body; i.e., areas of water surfaces not covered by vegetation and directly visible by satellite.

- **Water level:** The water level data on the portal are obtained from radar altimeter satellite data[2].

These indicators provide important information on the general water quality status of freshwater resources and indicate the health of associated ecosystems. Most importantly, these water quality indicators are essential for assessing impacts of human activities and climate change on a watershed. Negative changes in these water quality indicators are a sign of adverse impacts of anthropogenic pressures and global changes. Impacts of human activities on water quality include nutrient enrichment, eutrophication, and increased turbidity and suspended particulate matters in lakes and rivers due to agricultural runoff, sedimentation and erosion, and discharges of untreated, or insufficiently-treated, wastewater and industrial effluents. Data on water quality, water surface area and water levels provided by the portal are also crucial for the development of adaptation strategies for climate-resilient watershed management.

2. The altimeter data are processed by the French THEIA Data and Services Centre for Continental Surfaces within the HYDROWEB platform for data on water levels of large lakes, reservoirs and rivers in the world.

UNESCO World Water Quality Portal: Operational applications

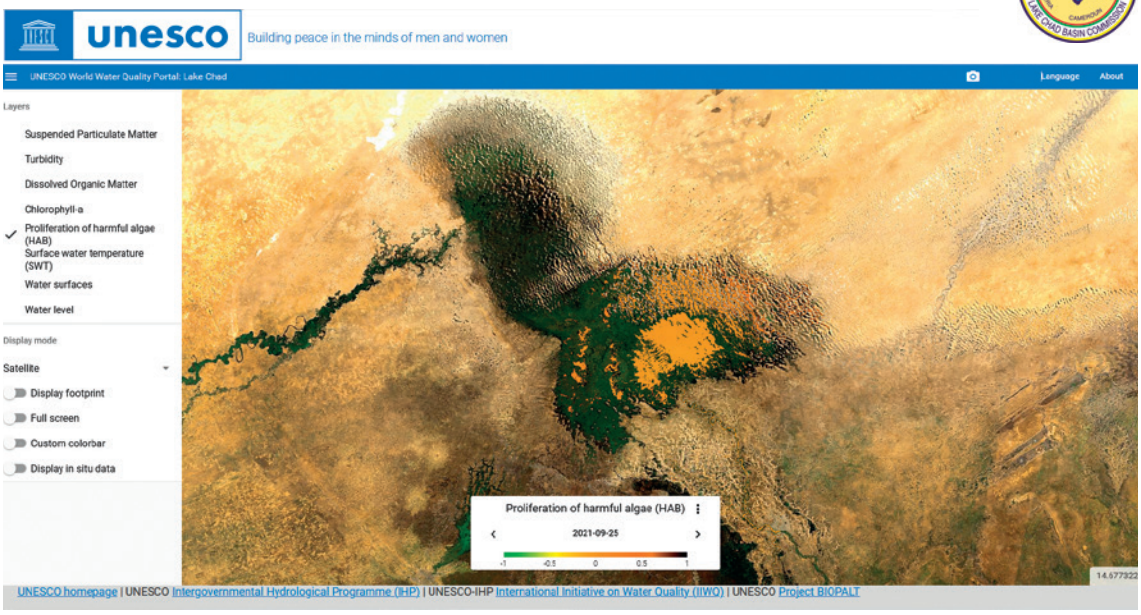
LAKE CHAD BASIN WATER QUALITY MONITORING

The first operational application of the UNESCO World Water Quality Portal has been developed for water quality monitoring in the transboundary Lake Chad Basin in Africa, in collaboration with the Lake Chad Basin Commission (LCBC) and the Man and Biosphere Programme (MAB) in the framework of transdisciplinary UNESCO Project "Biosphere and Heritage of Lake Chad" (BIOPALT) funded by the African Development Bank (AfDB).

Lake Chad is a unique freshwater resource. It is the fourth largest water body on the African continent and the third largest enclosed lake in the world. The lake provides freshwater for over 45 millions people and sustains livelihoods of local communities living around the lake. The Lake Chad Basin, extending over almost eight percent of the African continent, is shared by Cameroun, Central African Republic, Chad, Niger and Nigeria.

With very shallow water, Lake Chad is highly vulnerable to human impacts and climate change. Water quality of Lake Chad has declined during the past decades, with recurrent algal blooms and heavy metal pollution. Untreated, or insufficiently treated, municipal wastewater and industrial effluent discharges and seasonal agricultural runoff are the main sources of water pollution in the Lake Chad Basin. Not only is Lake Chad polluted, but its main tributaries Chari and Logone rivers are polluted and transport pollutants to the lake, impacting its water

UNESCO World Water Quality Portal for Lake Chad



Lake Chad water quality field measurements by Lake Chad Basin Commission experts

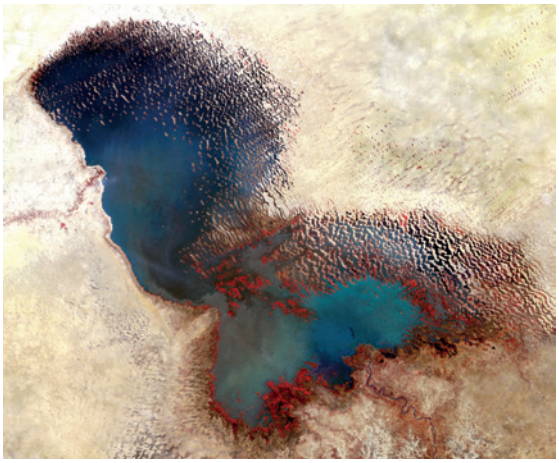
quality. Chari and Logone rivers provide over 90% of Lake Chad's water inflow. The lake's water level fluctuates depending on rainfall on the basin, making Lake Chad highly vulnerable to climate change. The lake's surface area has shrunk by drastically since the 1960s.

Protecting and improving Lake Chad's water quality is crucial for basin's water and natural resources, rich ecosystems, and biodiversity. The continued decline of Lake Chad 's water quality threatens not only basin's ecosystems, but also local populations' health and livelihoods. It is also a threat to the peace in the region. Water pollution will also diminish the availability of water resources for human uses. Hence, the protection of Lake Chad's water quality is central in providing local communities with clean water, preserving the lake's unique ecosystems and biodiversity, and safeguarding the health and livelihoods of millions of people, whose income and food supplies depend on the water and natural resources of the lake.

The UNESCO World Water Quality Portal for Lake Chad provides valuable data on water quality of the lake and its tributary Chari and Logone Rivers, which are essential for the development and implementation of policies and measures to improve water quality in the lake. The Lake Chad portal provides both historic and near real-time data from EO satellite images on key water quality indicators in Lake Chad and its tributary Chari-Logone Rivers, along with in-situ monitoring data. Satellite-derived data on Lake Chad's water quality are validated by in-situ data obtained from field measurement campaigns, carried out in Lake Chad and Chari-Logone in 2020-2021, by LCBC experts.

The portal provides data on the surface area and water level of Lake Chad, which are important for the monitoring of fluctuations in the water level and size of the lake in view of its extensive shrinkage over the past few decades. These data support the peaceful management of this shared water resource and

Lake Chad water surface variability



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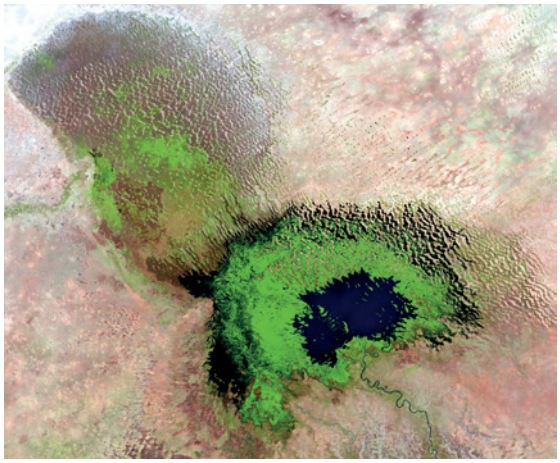

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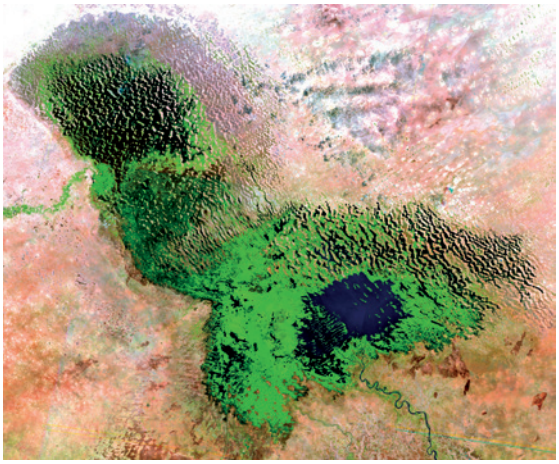

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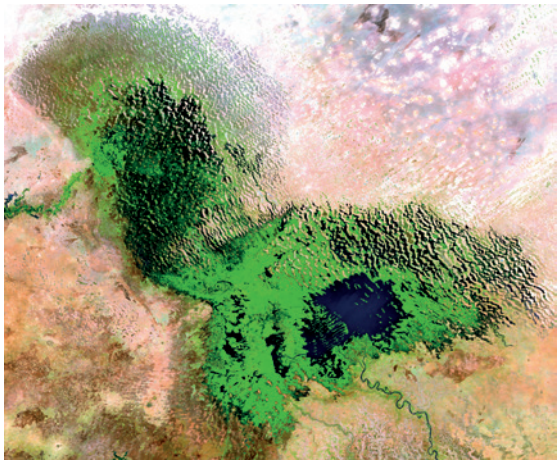

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transboundary water cooperation among the riparian countries of the Lake Chad Basin.

In addition to water quality data, the Portal, furthermore, promotes open access to data on Lake Chad water quality to all stakeholders, including local communities, whose traditional livelihoods such as fishing, livestock raising and spirulina algae harvesting depend on this precious water resource and on its water quality. Maintaining good water quality in Lake Chad is therefore vital for the preservation of these traditional livelihood practices and for the health of people living around the lake and in the basin area.

LA PLATA BASIN WATER QUALITY MONITORING

The UNESCO World Water Quality Portal is applied for operational water quality monitoring in a pilot area of the La Plata Basin in Latin America, in collaboration with the Intergovernmental Coordinating Committee (CIC) of the La Plata Basin Countries.

The transboundary La Plata Basin is shared by five countries, namely: Argentina, Bolivia, Brazil, Paraguay and Uruguay. The basin area covers southeastern Bolivia, southern and central Brazil, the entire country of Paraguay, most of Uruguay, and northern Argentina. Making up about one fourth of the continent's surface, it is the second largest drainage basin in South America and one of the largest in the world.

Supporting over 100 million people with water and natural resources, La Plata basin ecosystems are dominated by wetlands, floodplains and forest ecosystems. Among basin's many large rivers, La Plata's most important tributaries are Paraná, Paraguay and Uruguay rivers. The basin serves as the recharge area for the large Guarani aquifer system. As La Plata River water discharges into the Atlantic Ocean, it is also a major pathway of the transport of pollutants to the ocean.

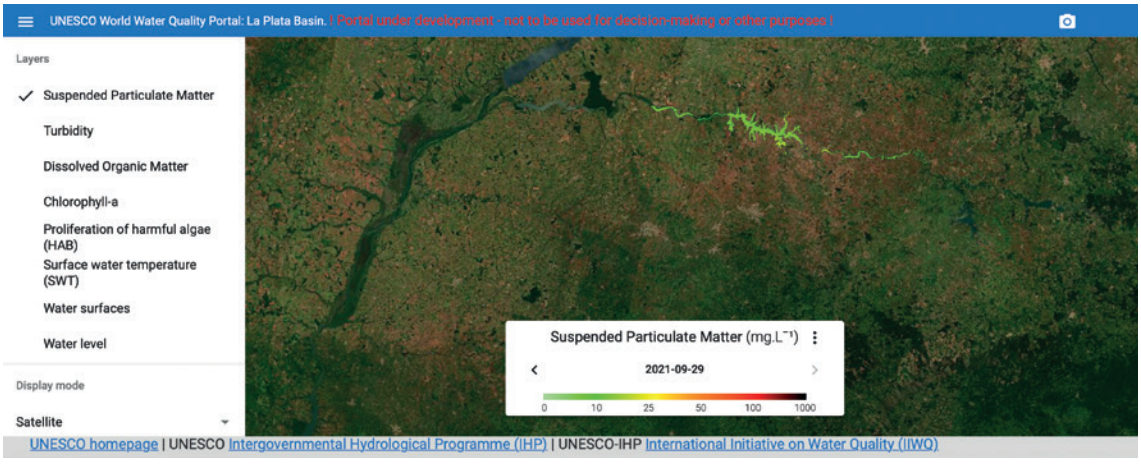
The La Plata Basin is central to the economy of the region and the riparian countries. Rapid economic development, coupled with climate change, have serious impacts on water quality of basin's river systems and ecosystems. Intensive agriculture is one of the major causes of water quality and ecosystem degradation in the basin. A significant portion of wastewater in the region is still discharged without treatment to water bodies, resulting in serious water quality deterioration in the basin.

Protecting and improving water quality in the La Plata Basin is an urgency. Further degradation of water quality and ecosystems of the basin due to increased pollution will pose serious threats to human health of populations, diminish water supplies, and jeopardise the region's economic development.

The La Plata portal provides valuable data on the ecological state and health of river systems of this vast transboundary basin. These data are crucial for the preservation and sustainable management of basin's water resources and ecosystems. The portal, furthermore, provides a valuable information basis for the development of science-based strategies and measures for climate adaptation and resilience in the basin.

UNESCO World Water Quality Portal for La Plata Basin

CIC Cuenca del Plata



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UNESCO WORLD WATER QUALITY PORTAL

The UNESCO World Water Quality Portal is an innovative tool for freshwater quality monitoring through satellite Earth Observation. The portal provides open access water quality data derived from EO satellites and field measurements, which are essential for science-based policy-making and management solutions to improve and protect water quality in the world's freshwater resources. The portal aims to support national water and environmental agencies and basin organizations in water quality monitoring for sustainable water management and the achievement of the SDG 6 "Clean Water and Sanitation for All" of the 2030 UN Agenda for Sustainable Development.
The portal is developed in the framework of the International Initiative on Water Quality (IIWQ) of the Intergovernmental Hydrological Programme (IHP) of UNESCO.
https://en.unesco.org/waterqualitymonitor

UNESCO-IHP INTERNATIONAL INITIATIVE ON WATER QUALITY

The International Initiative on Water Quality (IIWQ), established in 2012 by the endorsement of the Intergovernmental Council of the Intergovernmental Hydrological Programme (IHP) of UNESCO (Resolution XX-4), is a scientific cooperation initiative aimed at promoting knowledge generation and dissemination, research and innovative approaches, capacity building and science-based policy development to support countries to protect and improve water quality. The IIWQ is one of IHP's flagship initiatives.
https://en.unesco.org/internationalinitiativeonwaterquality

International Initiative on Water Quality

SCIENTIFIC PARTNERS

UNESCO IHP's International Initiative on Water Quality collaborates with the following scientific organizations, who provide the scientific and technical expertise necessary for the development of the UNESCO World Water Quality Portal and its applications in world's basins: French Space Agency (CNES) / French National Research Institute for Sustainable Development (IRD) / French Biodiversity Agency (OFB) /National Research Institute for Agriculture, Food and Environment (INRAE), France

cnes CENTRE NATIONAL D'ÉTUDES SPATIALES
IRD Institut de Recherche pour le Développement FRANCE
OFB OFFICE FRANCAIS DE LA BIODIVERSITÉ
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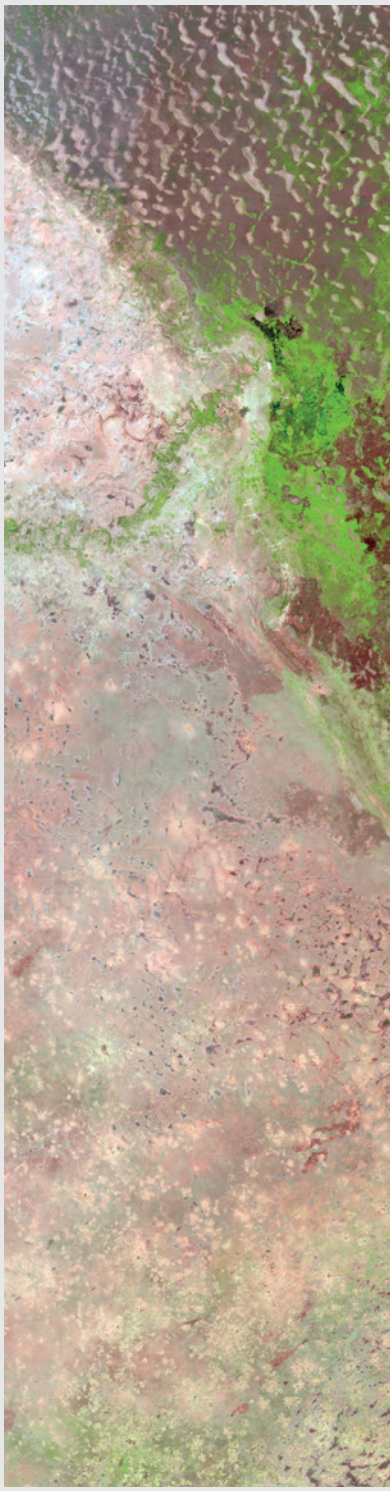

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