Global Water Quality Monitoring

GEMS/Water: A 50 year history

Since its inception, GEMS/Water, the water quality component of the Global Environment Monitoring System, has uniquely become one of the longest running operational United Nations programmes, initiated by four of its agencies, and supported actively by national partner institutions in their member states.

Today, improving ambient water quality globally is one of the ambitious targets set out in the 2030 Agenda for Sustainable Development (target 6.3). Comprehensive and up-to-date monitoring data on ambient water quality are indispensable for decision makers to ensure availability and sustainable management of water resources for both human uses and healthy aquatic ecosystems.

Reliable monitoring data on a world-wide basis and long-term temporal scale are also required for shaping global environmental policies and for science-based assessment of complex ecological issues.

This document presents the mission, activities and achievements of GEMS/Water during its 50 years history, summarizing reports and studies published at international level and by institutions and scientists in participating countries. It also looks ahead to some of the challenges for global water quality monitoring and the strategies and activities needed to help achieve good ambient water quality as the programme continues to evolve.

Objectives of GEMS/Water:

- Provide data and information to governments, the scientific community, and the public at large, on the world's freshwater resources through a global water quality database and information exchange platform.
- Strengthen the reliability of monitoring data through quality control of analytical procedures and advances in data quality assurance.
- Assess the status and trends in freshwater quality on fluxes of toxic chemicals, nutrients and other pollutants to the oceans, on pollutants related to human and aquatic ecosystem health, and on other environmental compartments.
- Support national and regional water quality monitoring networks through capacity development and training programmes.

Water Quality: What are the Issues?

Over the last 50 years, the crucial role of freshwater has become recognized as increasingly complex. Thus, water is no longer regarded as merely a natural resource, but also as a vital ingredient for human life and welfare, a social, economic and environmental good, and an essential component of the Earth's biogeochemical cycles. Moreover, with the impacts of climate change, freshwater is becoming the most threatened natural resource, with widespread droughts and fires, and more frequent catastrophic storms, precipitation and floods on all continents.

Photo credit: Adwoa Paintsil, Water Resources Commission, Ghana

Specific characteristics of water quality are required for each aspect of human development, including the use of water for human consumption, agriculture and food production. Sustainable management of terrestrial and aquatic ecosystems and their biodiversity, and of wetlands, the freshwater-ocean interface and healthy marine life, all depend on good water quality.

What has GEMS/Water contributed?

Knowledge of the status and trends in water quality at complex spatial and long-term temporal scales has become indispensable. Without good quality data and adequate monitoring coverage, over three billion people might be at risk world-wide due to the poorly known status of water quality in rivers, lakes and groundwaters. However, water quality monitoring should not be regarded as an end in itself but rather as the basis for preparing reliable quantitative scientific assessments and management of continental water resources and their quality issues.

At the time of the 1972 Stockholm conference, a new perception was evolving that freshwater resources could not be managed solely by hydrological measurements, but their quality characteristics were becoming increasingly important. Reliable water quality data were emerging as a vital knowledge requirement for water authorities, as well as for studying long-term pollution effects and environmental degradation. Responding to the need for harmonized monitoring at national, drainage basin and global scales, GEMS/Water developed its objectives. These have stood the test of time, although the activities have adapted, and the scope of the programme has broadened as scientific knowledge and societal needs have evolved.

Freshwater resources monitored by GEMS/Water:

- Rivers are spatial integrators over their drainage basin of the complex relations between human societies and their environment in the long-term, and are critical conveyors of material fluxes to the coastal zone.
- Lakes and reservoirs are temporal integrators of water quality, establishing natural baseline water quality, particularly in headwater lakes of river basins, and providing records of long-term trends archived in their bottom sediments.
- Groundwaters provide vital supply sources where surface water is scarce, seasonal or absent, or already polluted, and are increasingly important buffers against drought. They are vulnerable to diffuse pollution sources.

50 Years of GEMS/Water: Programme history

Gestation and birth of GEMS/Water: 1972 to 1977

At the1972 UN Conference on the Human Environment in Stockholm, UNEP and WHO were commissioned to launch a global health-related water quality monitoring programme as part of UNEP's Global Environment Monitoring System (GEMS). Concurrently, a global programme to assess river fluxes of nutrients and toxic substances to the oceans was launched. The interagency UNEP/WHO/UNESCO/WMO programme on water quality monitoring, known as GEMS/Water, was formally founded in December 1977.

Phase 1 Establishing a global harmonized monitoring network: 1978 to 1988

National authorities responsible for water quality monitoring were designated and monitoring strategies applicable to varying physical, social and economic situations, together with guidelines for monitoring network design, were introduced through regional workshops.

The National Water Research Institute (NWRI) of Environment Canada became the global operating centre for establishing a worldwide network of stations and harmonizing water quality data reporting: 450 stations were designated in 59 countries and routine data submission was achieved for 344 stations with over 500,000 data points. Participating laboratories were supported with analytical quality control by the U.S. Environmental Protection Agency (US EPA).

Phase 2 Consolidation of monitoring strategy and focus on assessment: 1989 to 2014

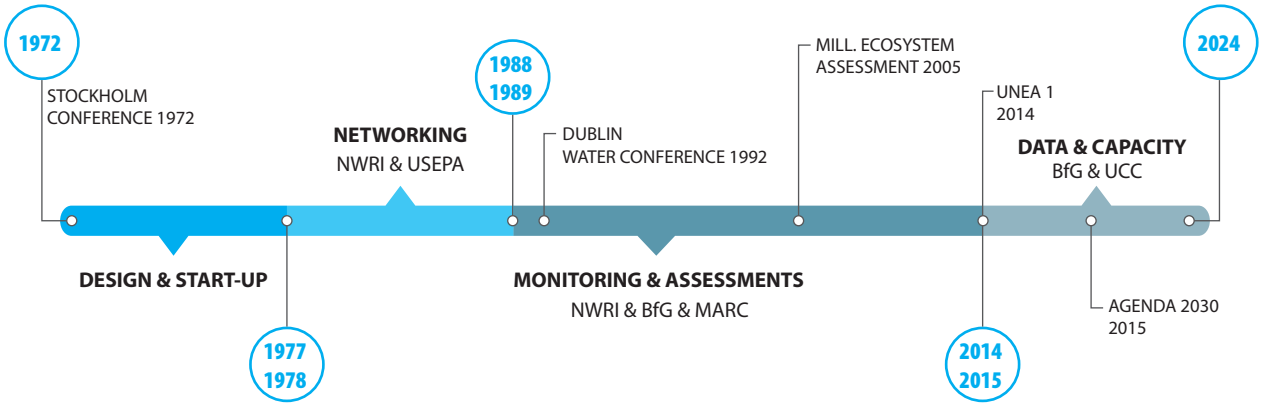
The global monitoring network was restructured towards assessment, targeted at 40-50 baseline stations in the least impacted basins, 300-400 trend stations with extended water quality records, and 60-70 global flux stations at the river/ocean interface. The number of stations reporting, and the number of data points collected, both increased tenfold. Water quality monitoring variables were revised to take account of water uses and pollution impacts.

Regional training workshops and laboratory performance evaluation studies were conducted regularly. Data processing software was developed first by NWRI and then by the German Federal Institute of Hydrology (BfG) and the first global assessments were performed on world river basins, ecosystems and human health, groundwater degradation and global pollution hazards.

Phase 3 Emphasis on data and capacity development: 2015 to present

Programme coordination was transitioned from Environment Canada to UNEP in 2014 with activities jointly implemented by UNEP, the GEMS/Water Data Centre and GEMS/Water Capacity Development Centre. The key functions of the Centres are:

- Capacity development to support monitoring and data generation in developing countries, centered at University College Cork (UCC), Ireland.
- Expanding and maintaining the global water quality database, GEMStat, located at the International Centre for Water Resources and Global Change (ICWRGC) at BfG, Germany. Providing data for national, regional and global assessments.
- Support to Member States worldwide with monitoring and reporting the UN Sustainable Development Goal indicator 6.3.2 for ambient water quality, provided by the Global Programme Coordination Unit at UNEP and supported by the two GEMS/Water Centres.



GEMS/Water: What was achieved?

GEMS/Water has contributed to the capacity for sound environmental monitoring of freshwaters globally and the preparation of assessments that have shaped environmental policymaking at global, regional and national levels. It has also made significant contributions to the assessment of the presence and effects of point and non-point pollution, persistent organic pollutants and emerging pollutants, and helped to shape approaches to ecosystem management.

Global Network of partners

Throughout its history GEMS/Water has maintained a network of relevant national agencies to act as national focal points, together with collaborating focal points in international bodies and water institutes. National focal points are responsible for providing water quality data to GEMStat, for liaising with GEMS/Water when assistance or advice is needed and for selecting and nominating recipients for GEMS/Water training and education programmes. There are well over 100 focal points distributed globally.

Monitoring methodology

A core principle of GEMS/Water has been to encourage monitoring activities which generate globally comparable water quality data of the highest standard possible and which meet the needs of water resource managers and policy makers. This is a complex process involving a chain of activities that are linked and interdependent. Methods for network design, sampling and analytical procedures, and data processing, were compiled in the GEMS/Water Operational Guide, first published in 1978 in English, French and Spanish, and last revised in 2004.

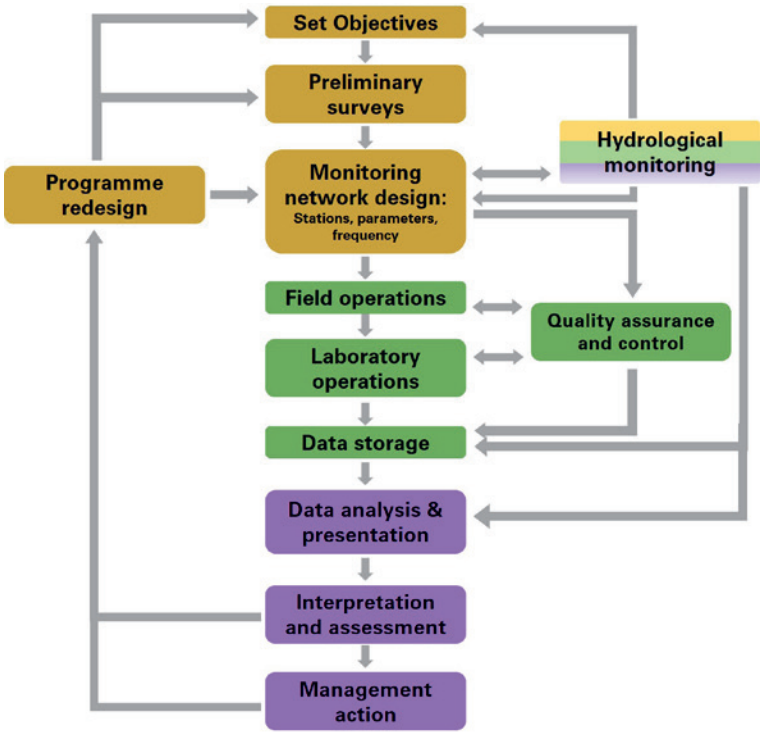
The detailed methodological guidelines produced by GEMS/Water have been used as toolboxes for establishing national water quality monitoring networks and the associated operational procedures, and have guided the development and delivery of capacity development activities.

Analytical Quality Control

Improvement of laboratory performance was a prime concern of GEMS/Water during phases 1 and 2 of the programme. During phase 1, calibration samples for ions, oxygen demand, nutrients and micropollutants were sent by the US EPA to 290 laboratories worldwide. This was the first ever international water chemistry analysis intercomparison on continental waters. A further four performance evaluation studies were conducted for multiple laboratories from 76 countries during phase 2, providing a measure of data variability in GEMStat. In phase 3, a broader approach to quality assurance has been promoted and participating laboratories have been encouraged to acquire accreditation from national, regional or international bodies.

Case study of application of methodology – India

In India, a three-tier programme was established in 1978 with designated GEMS/Water stations, a national aquatic resources system monitoring network, and a basin-wide management programme for the Yamuna River.
Today, there are 72 stations in GEMStat while ten times more stations have been established in rivers, lakes and groundwaters for the national programme. A referral laboratory supports analytical and internal/statistical quality control, and capacity development is provided through training in laboratory procedures, assessment studies and water management, allowing for pollution identification and trend analysis.



Data processing and reporting

Water quality data are the backbone for science-based assessments of global and regional water resources, the development of water quality indicators, indices and early warning of human impacts. Data gathered by official, verified national partners are fed into the GEMStat global database. During the 50 years of GEMS/Water, the network of monitoring stations has expanded continuously. At present, the data processing and reporting system includes over 13,000 stations, more than 100 variables and close to 4.5 million data points.

Since data collection started, the water quality data have been checked for their plausibility, homogeneity and intercomparability to take account of the differing analysis techniques and testing standards used around the world.

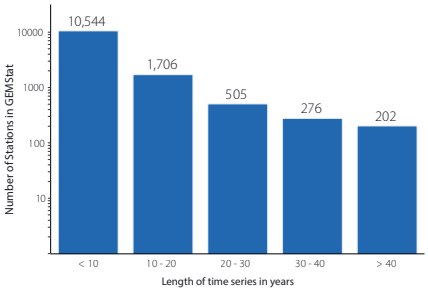
An essential element of the use of GEMS/Water quality data is its discoverability to provide users with the information they need. Visualization is another key element for improving water quality assessments and derived decision-making by visualizing data in their physical context including land use, proximity to cities or major factories. RAISON/GEMS was pioneering software developed by NWRI and which provided the first expert system in water quality assessment and monitoring, linking numeric data and descriptive knowledge.

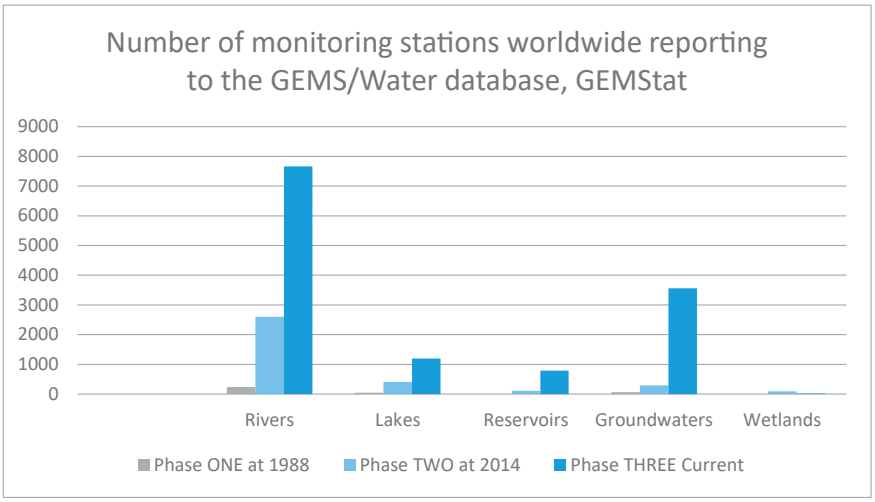
The visualisation facilities of the GEMStat data portal build on the concepts developed by RAISON/GEMS but have been adapted and streamlined to increase accessibility and to allow greater discoverability by a wide range of users.

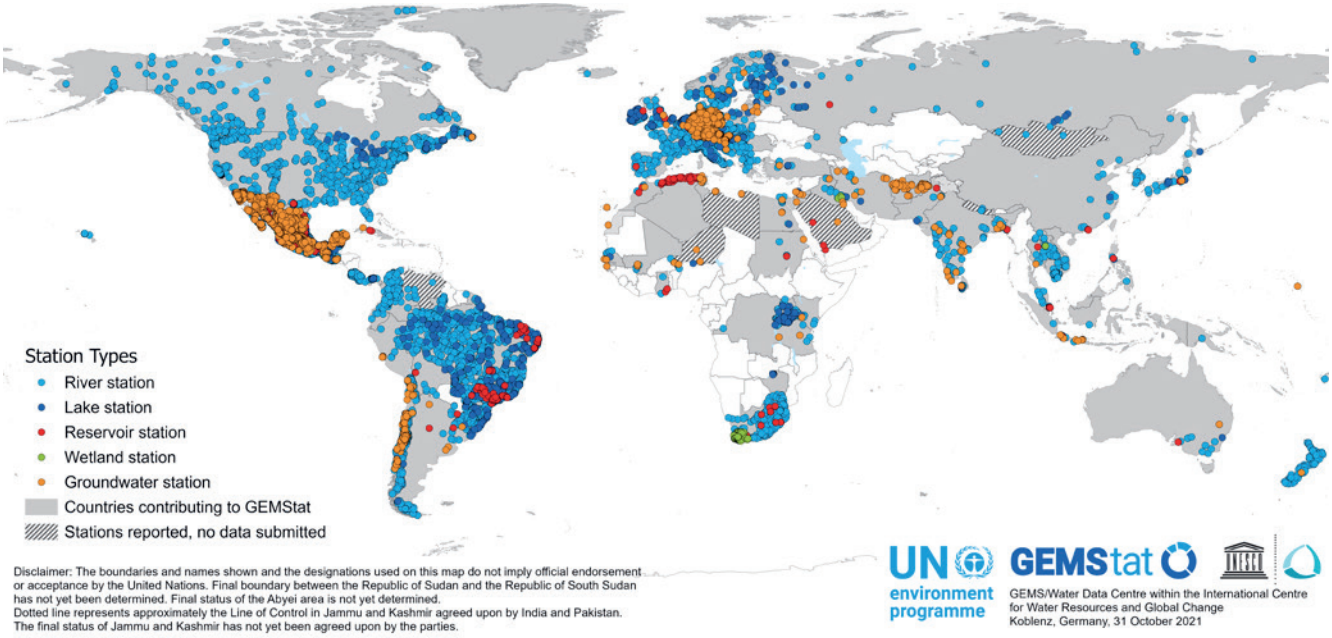
Interoperability is the third essential pillar of the GEMStat database, building on open standards and web services. This allows interaction with other global databases such as the Global Runoff Data Centre (GRDC). The development and application of the Loading Estimate Expert System allows the calculation of pollutant loads into the world oceans using a combination of river discharge and selected water quality variables (such as nutrients). Interoperability also allows quick links to sources of satellite-based information and to weather systems to provide early warning services at the most appropriate level. To meet the ever-increasing demand for water quality data, it is necessary to overcome institutional barriers to data collection, processing and sharing to fill spatial and temporal gaps in the data shared with GEMStat. This will be facilitated by further cooperation with partner countries and institutions, and by their active participation in the development of the data, in GEMS/Water's analysis-based services and in capacity development activities.

Note: During Phase 1 reservoirs were included with the lake stations, and wetlands were not yet part of the global monitoring network.

Number of Stations in GEMStat with given timeseries length







Capacity development

It was clear from the inception of GEMS/Water that the capacity to monitor and assess freshwater quality was far from equal in all countries worldwide. Therefore, capacity development was included from the start as a key activity to help facilitate the generation of high-quality data on rivers, lakes and groundwaters to support decision making at national, regional and global scales.

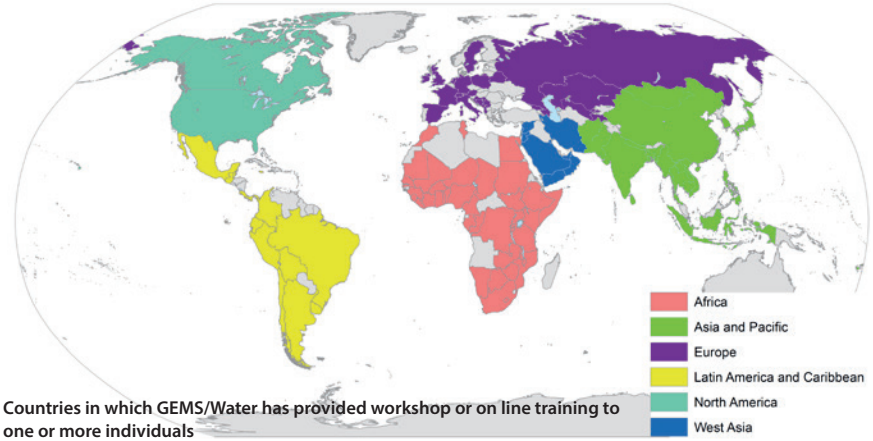
Capacity development activities have focused on providing advice and guidance, along with training and education, mostly free or subsidized for GEMS/Water participants from low-income countries. Advice and guidance comprise expert visits, consultations and technical documentation, and training and education take the form of workshops and longer educational programmes. In phase 3, consultations and training have included on-line and blended delivery modes, enabling many more recipients worldwide to benefit from the capacity development offered by GEMS/Water.

On behalf of UNEP, GEMS/Water now plays a key role in the implementation of Sustainable Development Goal indicator 6.3.2 for ambient water quality. It supports countries with capacity development for indicator monitoring activities, and with organizing and reporting their data and calculating national indicator values. GEMS/Water is also an active partner of the World Water Quality Alliance, leading the Capacity Development Consortium workstream, and is offering training courses and data support to the SDG6 Capacity Development Initiative created by UN-Water to accelerate the achievement of Agenda 2030.

"The GEMS/WATER MSc in Freshwater Quality Monitoring and Assessment has helped build my capacity, as result I am now leading a national freshwater quality monitoring programme"

In recent decades, over 400 individuals from nearly 120 countries have attended workshops or on-line training courses. Since its inception, GEMS/Water has developed a community of over 2,000 people with a common understanding of water quality issues and the associated requirements for monitoring, assessment and reporting. Since 2017, 58 postgraduate students have studied for the part-time, on-line GEMS/Water Postgraduate Diploma and MSc programme in Freshwater Quality Monitoring and Assessment.

For information see https://www.ucc.ie/en/gemscdc/onlinecourses/ and https://elearning.unep.org/



Countries in which GEMS/Water has provided workshop or on line training to one or more individuals

"[GEMS/Water] exposed me to the importance of monitoring and assessment of freshwater quality especially in the area of groundwater"

The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

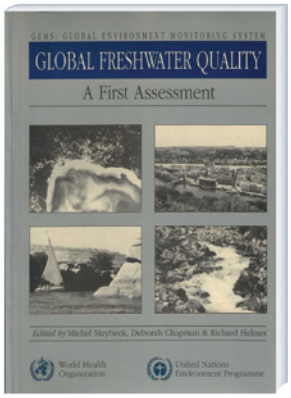
Assessments of water quality

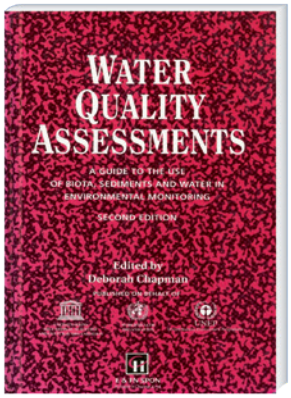
Several regional and global assessments of water quality have been produced by GEMS/Water and most of these had never been made before. "Global Freshwater Quality: A First Assessment", published in 1989, gave an overview of the status and functioning of rivers, lakes, reservoirs and groundwaters for salinization, heavy metals, eutrophication and sediment fluxes, among others. A companion study was published in Palaeogeography, Palaeoclimatology, Palaeoecology on "The quality of rivers: from pristine stage to global pollution". These two pioneering studies stimulated interest in global-scale river pollution, a field of research which has grown exponentially in the last 30 years, illustrating and quantifying the impacts of human activities on the aquatic environment in the Anthropocene era.

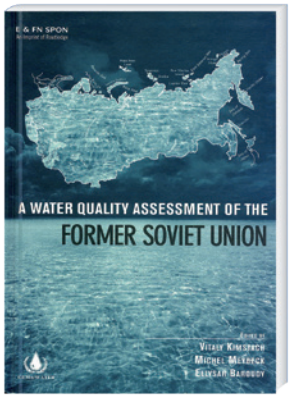
At the Dublin Conference on Water and the Environment in 1992, GEMS/Water presented a complete set of regional assessments, which were used again in 2005 for the Millennium Ecosystem Assessment. Also in 1992, GEMS/Water scientists published the guidebook "Water Quality Assessments" (updated in 1996), which has been sold and used worldwide and is still among the top cited references in this field, with more than 200 citations per year.

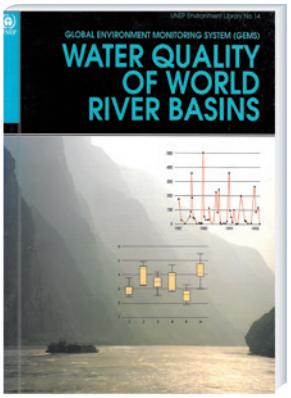
GEMS/Water has been a pioneer in collecting water quality data at river mouths, allowing for the calculation of fluxes to the oceans of pollutants such as nutrients, organic compounds, pesticides and suspended matter. In 1996 the GEMS/Water database was merged with other river registers, such as those of IGBP-LOICZ, to create GEMS/GLORI, a global inventory of 550 rivers presenting pristine and current water quality data, and which is still widely used by earth system scientists and coastal oceanographers.

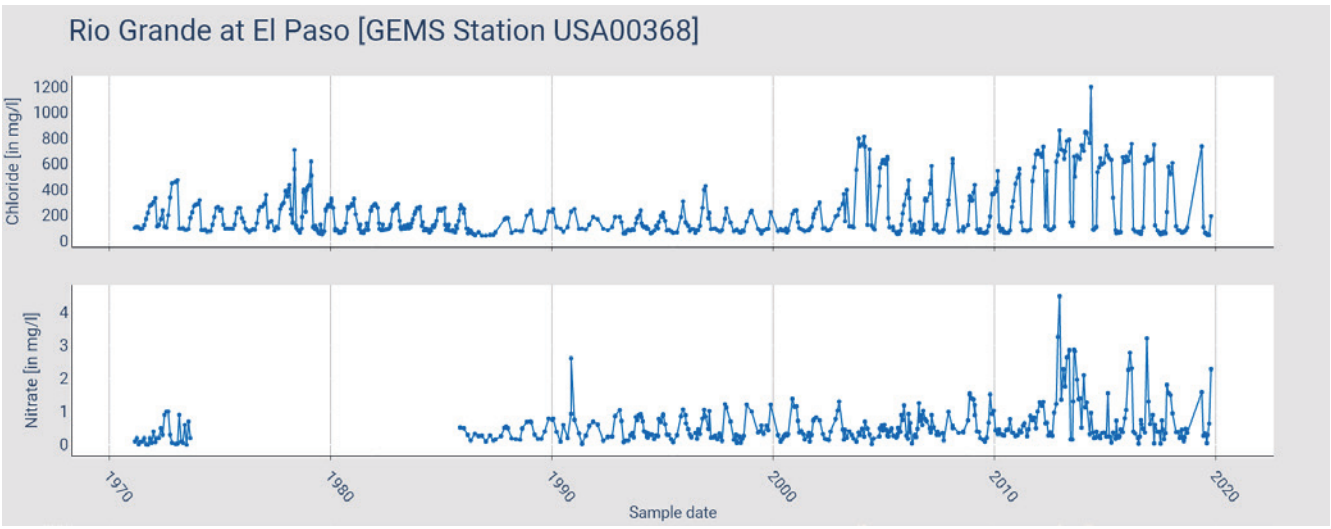
In 1998, an assessment of freshwater quality for the Former Soviet Union was prepared by GEMS/Water for rivers, lakes (Baikal, Aral) and groundwaters, covering a continental scale territory of 20 million km^2 and most climatic belts, relief types and human impacts. River basin case studies, stretching from the Danube to the Amur, from Arctic rivers to Georgia, were based on some of the longest water quality records available globally.











In the Rio Grande-Rio Bravo basin, shared between USA and Mexico and highly regulated by reservoirs, salinization is a major concern for water quality management. Both chloride and nitrate show clear seasonal fluctuations, which are amplified in later years.

GEMS/Water: Looking ahead

GEMS/Water has maintained its core activities of monitoring design, water quality database, capacity development and networking throughout its 50-year history. The ideas and approaches developed over this period and in response to emerging requirements will shape the programme's future. Based on its sound conceptual foundations and operational strengths, new approaches are being developed that use digital technology and embrace societal engagement to add value and improve accessibility and relevance of water quality monitoring data. The importance of the past activities of GEMS/Water and its ongoing contribution to environmental assessments is reflected in UNEP's Data Strategy, which includes scientific assessment of the environment, global outlook reports, global environmental monitoring systems, and serving as a knowledge hub.

GEMS/Water is firmly anchored in the UNEP Mid-Term Strategy (MTS) and supports the three pillars of the strategy - Climate, Pollution and Nature Actions - as a cross-cutting activity. To do this, GEMS/Water will need to take account of all sectors of society: public, private, research and cultural, so that its activities help guide societal action and financial investments at global, national and sub-national scales. In practical terms, this will mean strengthening efforts to include citizen science and private sector monitoring information.

Many of the major challenges for water quality monitoring still persist, and are not confined to GEMS/Water. Properly characterising the three-dimensional quality of groundwaters presents specific challenges arising from the physical complexity and relative inaccessibility of aquifers. Effective groundwater quality monitoring needs greater spatial density but usually lower sampling frequency than rivers. For lakes and reservoirs, sediment archives and innovative approaches, including remote sensing, offer new opportunities to improve their assessment. A special need is the monitoring of micro-pollutants such as those from medical residues and mutagenic substances. Institutionally, there are still unclear responsibilities for monitoring, a lack of financing and technical capacity of monitoring systems, and a reluctance to share data. Consequently, the GEMS/Water database has limited capacity to support global or regional assessments and needs to increase its coverage, particularly for lakes and groundwaters. Wetland monitoring should also be included in the programme.

A key challenge for the future is raising awareness, at both community and policy levels, that the quality of rivers, lakes and groundwater is of critical importance for socioeconomic development and human health and welfare. Progress towards Agenda 2030, and especially SDG 6 for water, will not be made without greater effort to expand water quality monitoring and assessment at a global scale and by engaging society at all levels. Water quality has both scientific and social components, the capacities of which vary greatly from country to country. GEMS/Water is well placed to develop these capacities and is ready and willing to work in partnership with other organizations.

Further Information

- Monitoring Water Quality: GEMS/Water Programme Website: www.gemswater.org
- UNEP GEMStat Data Portal, International Centre for Water Resources and Global Change, GEMS/Water Data Centre. Federal Institute of Hydrology, Koblenz, Germany. GEMStat Website: https://gemstat.org
- UNEP GEMS/Water Capacity Development Centre https://www.ucc.ie/en/gemscdc/
- UNEP GEMS/Water documents https://communities.unep.org/display/gemswater/Archives
- Sustainable Development Goal 6: https://www.unep.org/explore-topics/sustainable-development-goals/why-do-sustainable-development-goals-matter/goal-6; https://www.sdg6data.org/
- Water Quality Assessments: a guide to the use of biota, sediments and water in environmental monitoring. Edited by Deborah V Chapman. Published on behalf of UNESCO, WHO and UNEP by E&FN SPON, 1992 and 1996 (second edition) https://apps.who.int/iris/handle/10665/41850
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