

IAEA BULLETIN

INTERNATIONAL ATOMIC ENERGY AGENCY

The IAEA's flagship publication | September 2025 | www.iaea.org/bulletin

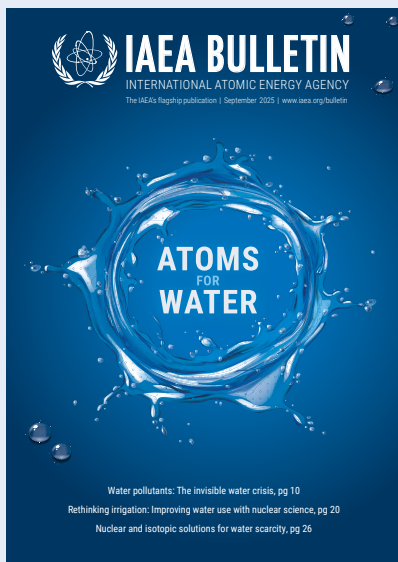


ATOMS FOR WATER

Water pollutants: The invisible water crisis, pg 10

Rethinking irrigation: Improving water use with nuclear science, pg 20

Nuclear and isotopic solutions for water scarcity, pg 26



IAEA BULLETIN

is produced by the

Office of Public Information and Communication

International Atomic Energy Agency

Vienna International Centre

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IAEA BULLETIN is available online in all

United Nations languages at

www.iaea.org/bulletin

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**Atoms for Peace
and Development**

The mission of the **International Atomic Energy Agency (IAEA)** is to help prevent the spread of nuclear weapons and to help all countries — especially in the developing world — benefit from the peaceful, safe and secure use of nuclear science and technology.

Established as an autonomous organization under the United Nations in 1957, the IAEA is the only organization within the UN system with expertise in nuclear technologies. The IAEA's unique specialist laboratories help transfer knowledge and expertise to IAEA Member States in areas such as human health, food, water, industry and the environment.

The IAEA also serves as the global platform for strengthening nuclear security. The IAEA has established the Nuclear Security Series of international consensus guidance publications on nuclear security. The IAEA's work also focuses on helping to minimize the risk of nuclear and other radioactive material falling into the hands of terrorists and criminals, or of nuclear facilities being subjected to malicious acts.

The IAEA safety standards provide the fundamental principles, requirements and recommendations to ensure nuclear safety and reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from the harmful effects of ionizing radiation. The IAEA safety standards have been developed for all types of nuclear facilities and activities that serve peaceful purposes, as well as for protective actions to reduce existing radiation risks.

The IAEA also verifies through its inspection system that Member States comply with their commitments under the Nuclear Non-Proliferation Treaty and other non-proliferation agreements to use nuclear material and facilities only for peaceful purposes.

The IAEA's work is multi-faceted and engages a wide variety of partners at the national, regional and international levels. IAEA programmes and budgets are set through decisions of its policymaking bodies — the 35-member Board of Governors and the General Conference of all Member States.

The IAEA is headquartered at the Vienna International Centre, Vienna, Austria. Field and liaison offices are located in Geneva, New York, Tokyo and Toronto. The IAEA operates scientific laboratories in Monaco, Seibersdorf and Vienna. In addition, the IAEA supports and provides funding to the Abdus Salam International Centre for Theoretical Physics, in Trieste, Italy.

Saving our most precious resource through the power of nuclear science and technology

By Rafael Mariano Grossi, IAEA Director General

Water is the world's greatest shared resource. It has underpinned the growth and development of ecosystems and human civilizations. But now this life-enabling reserve is under pressure.

Climate change is affecting the availability of water. As global temperatures rise, glaciers are melting, lakes are evaporating, and rising seas are salinizing coastal groundwater. More extreme and more frequent weather phenomena are making water supply more unpredictable.

As the world's population continues to increase, there is rising demand for water for agriculture, household use and sanitation, industrial activities and power generation. Meanwhile, water pollution is increasing at unprecedented rates, with a growing number of contaminants causing harm throughout the water cycle.

To protect and sustain our water resources — and thereby also our societies and economies, our health and the health of our planet — we first need to understand them. This means measuring, monitoring and tracing water and its pollutants. We need data, water-saving technologies — especially in agriculture and industry — and effective water management systems, plus collaboration and coordination across sectors and national borders.

“Atoms for Water” is the theme of this year's IAEA Scientific Forum. Nuclear sciences and technology offer powerful tools to understand and protect our water resources. That is why water has been a priority area of the IAEA's work since the very beginning.

For 65 years, the IAEA has been monitoring precipitation through the Global Network of Isotopes in Precipitation, providing baseline data for hydrological research and water resource management. The IAEA's Isotope Hydrology Section and its laboratory have been studying isotopes in water to identify its age and source, track its movement and assess its quality. This can help determine how much water we have, how long it takes for groundwater to replenish, and whether we

are using it efficiently. It also helps identify and track water contaminants.

The IAEA also has a long history of developing and disseminating technologies and methods for monitoring, measuring, preserving and sustaining water resources using nuclear and isotopic techniques. This issue of the *IAEA Bulletin* covers some of our work in these areas, such as combining data from cosmic ray neutron sensors with drip irrigation technology to make agricultural water use more efficient, and treating wastewater with electron beam technology to make it easier to collect and remove microplastics.

It also describes how IAEA scientists are using artificial intelligence and other cutting-edge technologies to advance analysis and modelling throughout the water cycle, providing decision makers with better information for water resource management.

Pollution, especially plastic pollution, blights our water systems and oceans. In 2021, I launched the Nuclear Technology for Controlling Plastic Pollution (NUTEC Plastics) initiative to harness the power of nuclear science in addressing the global plastic crisis by improving plastic recycling and reducing marine plastic pollution. In 2023, I launched the Global Water Analysis Laboratory (GloWAL) Network to empower countries to manage their water resources effectively and to foster collaboration and innovation in water research. Through our technical cooperation programme, the IAEA provides countries with training, expertise and equipment to enhance their national capacities for water research, monitoring and management.

We share a global water system, where developments in one region can affect water resources in another. To effectively manage the world's water resources, we need to understand these connections and we need to cooperate. By working together, we can build a more circular and sustainable water economy that protects our environment and benefits us all.



“We share a global water system, where developments in one region can affect water resources in another. To effectively manage the world's water resources, we need to understand these connections and we need to cooperate.”

– Rafael Mariano Grossi,
IAEA Director General



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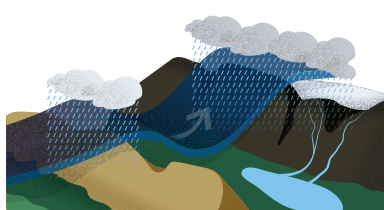
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Water is everyone's responsibility

Interview with Retno Marsudi, the United Nations Secretary General's Special Envoy on Water

The United Nations Secretary General's Special Envoy on Water, Retno Marsudi, shares her views on what needs to be done to ensure a water-resilient future. A global advocate for water issues, she supports efforts to mobilize action and resources and to strengthen international cooperation to advance the global water agenda. From 2014 to 2024, she served as Indonesia's Minister for Foreign Affairs.



Talking about water is not just talking about infrastructure or systems — it is talking about survival. It is about protecting the foundation of life and livelihoods.

— Retno Marsudi,
the UN Secretary General's
Special Envoy on Water

Q: What does water mean to you personally?

A: Water has always been deeply personal to me. As a woman, I understand how water-related challenges disproportionately affect women and girls. In many parts of the world, water scarcity and limited access to safe water place an unequal burden on them, forcing them to travel long distances to fetch water for their families.

However, women are also leaders of change. I believe — and evidence consistently shows — that women's leadership in water leads to more sustainable and equitable outcomes, not only in water but across all other development sectors.

I also believe that responsibility for water management goes beyond global commitments or institutional mandates. It speaks to our very existence, our dignity, and the life of future generations. Talking about water is not just talking about infrastructure or systems — it is talking about survival. It is about protecting the foundation of life and livelihoods.

That is why the responsibility to implement global water commitments carries great weight. It is not just about policy. It is about improving lives — everywhere, for everyone, especially for those most often left behind.

Q: What do you see as the key priorities for achieving sustainable water resources for our planet?

A: Water is essential to life, and today our world's water systems are under stress like never before. An estimated 2.4 billion people live in countries experiencing water stress. In 2022, at least 1.7 billion people globally relied on drinking water from contaminated sources.

Climate change and extreme weather events are only exacerbating this situation, with the year 2024 being the warmest on record. Urgent and multifaceted action is needed, including strengthening research, building capacities, empowering women and youth to foster innovations, and many more efforts.

At the core of all these efforts is one indispensable element: international cooperation, grounded in global solidarity.

International cooperation is key to translating global commitments into concrete actions. Unfortunately, water financing remains insufficient and is declining globally. Meeting future demands for water and water infrastructure will require an estimated \$6.7 trillion by 2030, and over \$22 trillion by 2050.

To achieve a water-secure future, we must prioritize bold international collaborations — particularly in financing, technology development, and capacity building for those most in need.

Q: What are the most effective approaches to accelerating efficiency, resilience and sustainability in water management?

A: In my dialogues with countries and water stakeholders, I consistently emphasize that water is everyone's responsibility. No single individual, institution or country can address global water challenges alone. Governments, the private sector, academia, civil society organizations and others must all be inclusively engaged in shaping and implementing water management efforts.

A multi-stakeholder approach strengthens ownership by ensuring that all actors are on board in the planning, implementation and evaluation of water solutions. It draws upon

the diverse expertise and capacities that each stakeholder brings to the table.

Equally important is a multisectoral approach that integrates water across all dimensions of development. Through integrated water resource management, water can serve as a unifying solution to multiple global challenges, including poverty eradication, climate resilience, food and energy security, disaster risk reduction, and the empowerment of women and youth.

These approaches depend on a robust operational framework. This is where the ‘Triple A’ principle (advocacy, alignment, and acceleration of actions) becomes critical: advocacy to elevate water as a common priority; alignment to bring coherence in all water-related initiatives; and acceleration to fast-track innovation and action.

Lastly, we must not miss the chance to capitalize on the transformative role of technology, in accelerating the efficiency, resilience and sustainability of water management. With technology we can ensure the effective management and use of water. We can produce more — more food, more energy, more economic growth — with less water.

Q: Where do you see the greatest potential for the IAEA to help address water challenges?

A: With its strong focus on research, development and capacity building, the IAEA has a lot to offer.

Isotope hydrology stands out as a powerful example of the transformative potential of nuclear sciences to address complex water-related challenges. The ability of isotope hydrology to precisely trace the origin, age and quality of water makes it a game-changer in water resource management.

Isotope hydrology also offers us a deep understanding of the world’s water systems,

not only enabling us to respond to existing challenges, but also to anticipate and prepare for future water-related disaster risks. It strengthens early warning capacities and long-term water resilience planning.

I encourage the IAEA to continue to prioritize the application of nuclear sciences in the most pressing water challenges, especially those disproportionately affecting developing countries such as drought and water scarcity, flood risks from extreme weather and water pollution. Through the application of nuclear science and technology, I believe the IAEA will contribute to enhancing global water resilience.

Q: What are your hopes and expectations for the 2026 United Nations Water Conference?

A: I am guided by the hopes and expectations consistently expressed by countries and water stakeholders around the world.

Expectations for the 2026 United Nations Water Conference are high. It will be a critical milestone in advancing global water progress and a pivotal opportunity to accelerate the achievement of Sustainable Development Goal 6 (clean water and sanitation).

The conference is also expected to inform and shape the future of the global water agenda beyond 2030. This reflects a growing awareness that ensuring our water future requires not only immediate actions but also a clear vision for tomorrow, not just for the world’s people but also for the planet.

The success of the 2026 United Nations Water Conference relies heavily on the strong commitment of countries and water stakeholders around the world. Meaningful and actionable results can only be attained through inclusive and transparent preparation processes. I am keen to collaborate with the IAEA towards this goal.



Central Asia takes the lead on glacier preservation

By Mary Albon

In Central Asia and other mountainous regions around the world, glaciers are melting faster than ever. Rising temperatures are shortening winters and prolonging summers, which in turn leads glaciers to retreat.

Glaciers store about 70% of Earth's freshwater, which nearly two billion people depend on for drinking water, agriculture, industry and energy production. Glaciers also support ecosystems and are local 'climate stabilizers', protecting against heat absorption by reflecting solar radiation back into space.

As glaciers continue to shrink and even disappear, the water cycle is becoming more unpredictable, affecting water supply across the world. This loss is not just an environmental problem, but also an economic one, impacting livelihoods of millions of people. The United Nations Environment Programme estimates that the depletion of glacier-fed freshwater supplies could jeopardize \$4 trillion of global gross domestic

product by disrupting agriculture, urban water supplies and energy production.

The impact of climate change on Central Asia's glaciers

In Central Asia, the situation is becoming dire. "The consequences of global climate change are felt in each of our countries," said the President of Uzbekistan, Shavkat Mirziyoyev, at the Sixth Central Asian Summit in August 2024. "Rising temperatures, melting glaciers, floods, droughts, dust storms and many other challenges continue to cause serious damage."

According to a 2022 report by the Eurasian Development Bank, the region's temperatures are increasing almost twice as fast as the global average, increasing desertification and hastening glacier melt.

"To date, more than 1000 of Tajikistan's 14 000 glaciers have completely melted,"

Yaks in a mountain valley of Central Asia.

(Photo: AdobeStock)



said the President of Tajikistan, Emomali Rahmon, at the first High-Level International Conference on Glaciers' Preservation, held in Dushanbe in May 2025. "Over the past few decades the total volume of glaciers in our country — which make up more than 60% of the water resources in the Central Asian region — has decreased by almost a third."

Kyrgyzstan's glaciers have not been spared either: the area covered by glaciers has decreased by 16% over the past 50 to 70 years.

"If this trend continues, a significant part of the glaciers may disappear by the end of the century," said the President of Kyrgyzstan, Sadyr Japarov, at the 29th United Nations Conference on Climate Change (COP29) in 2024. "This is not just statistics, this is a direct threat to the lives and well-being of millions of people who depend on glaciers as a source of fresh water."

Halting the crisis

At the urging of Tajikistan, the United Nations General Assembly declared 2025 the International Year of Glaciers' Preservation

to raise awareness about melting glaciers and advocate for policies and measures to preserve them. The official launch took place in New York on 21 March 2025, marking the first annual World Day for Glaciers.

A few weeks later, the High-Level International Conference on Glaciers' Preservation resulted in the adoption of the Dushanbe Glaciers Declaration, which expressed concern that the continuing loss of glaciers, ice sheets, permafrost and snowpack could have irreversible effects on certain ecosystems and detrimental impacts on the environment, societies and economies.

The declaration called for a global inventory of glaciers and other perennial ice and snow masses; integrated approaches to climate change mitigation, adaptation and resilience for sustainable water management; scientific cooperation on mountain cryosphere monitoring and research, with the findings made available to all stakeholders; and capacity-building efforts bridging science, policy and traditional knowledge to train the next generation of glacier scientists and practitioners.



International cooperation on glacier monitoring and research

This year also marks the start of the Decade of Action for Cryospheric Sciences, a global effort to advance research and international collaboration and raise awareness of the importance of Earth's frozen regions — the cryosphere — including glaciers.

Glacier preservation is a key component of a comprehensive regional strategy for climate change adaptation in Central Asia that has been jointly developed by Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan.

“No country can cope with the challenges of climate change alone,” said President Japarov. “We need solidarity, cooperation and exchange of experience.”

As part of this regional strategy, the five countries are enhancing their national capacities for glacier monitoring, working together on joint monitoring and creating a comprehensive inventory of the region's glaciers.

Data on glaciers are of key importance for scientific evaluations and for decision making on adaptation and mitigation strategies. In 2025, Tajikistan opened the first isotope hydrology laboratory in Central

Asia for conducting research on glaciers, with support from the IAEA's technical cooperation programme. The IAEA provided the laboratory with equipment for studying glaciers in field conditions and trained scientists to use it. Tajikistan has also proposed the establishment of a regional network within the IAEA's Global Water Analysis Laboratory (GloWAL) Network; the IAEA will work with the Central Asian countries to develop a roadmap for it.

“In the arid lands of Central Asia, isotope hydrology bridges the past and present,” said Yuliya Vystavna, an IAEA isotope hydrologist. “It traces ancient climate imprints and current glacier melt to guide sustainable water use in a region where every drop counts.”

The IAEA's work on glaciers

The IAEA has been working with mountainous countries to monitor and measure glacier retreat for over a decade. Kazakhstan and Uzbekistan are among 12 countries taking part in a new IAEA coordinated research project that uses isotope hydrology tools to improve evaluation of the complex processes related to glacier retreat and its broader impact on the availability of water resources.

Despite their importance in terms of water supply, glacier melt, snowmelt, precipitation and other water sources are not well measured in many frozen regions. The IAEA project will support countries in collecting accurate and reliable data to better understand glaciers and the recharge capabilities of local and regional water resource systems. This will inform sustainable water management strategies for mountainous regions and support improved water resource planning for downstream communities.

Tajikistan, Uzbekistan and seven other countries are studying snow cover and mountain glaciers as part of a new IAEA regional technical cooperation project to support evidence based management of transboundary water resources. A key aim

Preparing samples of glacier meltwater for analysis in Tajikistan's new isotope hydrology laboratory.

(Photo: Y. Vystavna/IAEA)



of this work is to preserve the isotopic characteristics of glaciers that are close to disappearing.

Through the Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture, the IAEA is studying the impact of glacier retreat on soil and water resources using advanced nuclear and isotopic techniques. Tools such as cosmic ray neutron sensors and isotopic tracers enable precise, real-time monitoring of snow accumulation on glaciers and assessments of the redistribution of sediments from deglaciated areas to downstream rivers and lakes. Through

its technical cooperation programme, the IAEA trains scientists from the Andes to the Himalayas to use these techniques for glacier monitoring, thereby supporting the development of site-specific, evidence based climate change adaptation strategies.

“By combining nuclear science with local expertise, we empower scientists and policymakers to turn data into action for climate resilience,” said Gerd Dercon, Head of the Joint FAO/IAEA Centre’s Soil and Water Management and Crop Nutrition Laboratory.

Pamir Mountains, Kyrgyzstan.

(Photo: AdobeStock)



Water pollutants: The invisible water crisis

By Emma Midgley

Water is vital for food security, human health and economic development. But as populations grow and climate change intensifies, pollution is increasing throughout the water cycle.

Water pollutants come in many forms, which are often invisible. Fertilizers, plastics, sewage, pharmaceuticals, hormones, industrial chemicals, petrochemicals, heavy metals and mining run-off are among the most common.

A key hurdle for countries seeking to improve water quality is the lack of data on their water resources. Nuclear and isotopic techniques can help us understand where water pollution originates and provide science-backed solutions to mitigate this challenge.

The nitrogen problem

Nitrogen is a leading source of water pollution, with potentially serious effects on human health and the environment. Major sources of nitrogen pollution include fertilizers, wastewater and industrial discharges. While nitrogen fertilizer has boosted food production over the past century, around 80% of it is lost to the environment.

“Nitrogen pollution, especially from nitrates, is a major threat to rivers, lakes, groundwater and coastal waters,” said Ioannis Matiatos, an isotope hydrologist at the Hellenic Centre for Marine Research in Greece. “Tracing where nitrate contamination comes from is essential

for protecting aquatic systems and guiding efforts to clean up polluted areas.”

Nitrates are the most soluble form of nitrogen, meaning they can easily seep into groundwater, lakes and rivers. If concentrated in drinking water, nitrates can impair the blood’s ability to transport oxygen around the body. Nitrogen pollution also causes water to become overly enriched with nutrients, leading to harmful algal and plant growth in lakes and rivers. According to the United Nations Environment Programme, nitrogen pollution is the biggest driver of biodiversity loss after habitat destruction and greenhouse gas emissions.

Climate change is exacerbating the impact of nitrogen pollution. Earth’s warming climate is resulting in more wildfires, leading to increased use of fire retardants containing large quantities of nitrogen based compounds that leach into water sources. Meanwhile, lakes and rivers are warming as the planet heats, promoting the growth of types of vegetation that can harm ecosystems and the environment. Warmer lakes filled with algae can emit nitrous oxide, a greenhouse gas, while colder lakes remove nitrogen from the nitrogen cycle and store it over long periods.

Decoding nitrogen pollution through isotopic analysis

The IAEA is using isotopic techniques to help identify the sources of nitrogen pollution. As part of this research, it has worked with the University of Massachusetts to develop cheaper,

Single-use plastic bag floating by a coral reef in Bali.

(Photo: N Bertolt Jensen / Ocean Image Bank)



safer and faster methods to trace the origin of nitrogen pollution in rivers, lakes and seas.

“Nitrate isotope techniques are a powerful tool because they help us identify nitrate pollution sources and understand how nitrogen is used and transformed in nature,” Matiatos said.

Through its technical cooperation programme, the IAEA is helping countries build capacity in isotopic techniques to study nitrogen pollution everywhere from the Italian Alps — where glacial meltwater feeds into nearby lakes — to the megacity of Kolkata, India.

The IAEA also uses isotopic and nuclear techniques to help countries use fertilizer more efficiently, enhance carbon and nitrogen capture in agro-ecosystems, and investigate how legume crops, or integrated cropping-livestock systems, can reduce the need for chemical fertilizers.

Compounds of emerging concern

Contaminants such as pharmaceuticals, hormones, industrial chemicals and personal care products are increasingly being detected in surface water systems. These contaminants usually originate in municipal, industrial and domestic wastewater. Known as ‘compounds of emerging concern’, they have only recently been identified as potential threats to the environment and are not yet widely regulated by national or international laws. Their effects in freshwater are not well understood, but it is believed that they may disrupt hormones and contribute to antibiotic resistance in humans and animals and negatively impact aquatic ecosystems.

However, compounds of emerging concern can be used to better understand sources of nitrate pollution because they occur together in polluted water systems. The IAEA is working with scientists around the world to trace the origins and pathways of nitrate pollution in surface water and groundwater by linking nitrate isotopes to these compounds.

“Compounds of emerging concern are ideal tracers for faecal contamination as they are usually linked to a specific source and are detectable in contaminated environmental samples,” said Yuliya Vystavna, an IAEA isotope hydrologist.



(photo: AdobeStock)

Radiation technology for wastewater treatment

Removing micropollutants such as microplastics, persistent organic contaminants and pharmaceuticals from wastewater is critical to achieving and maintaining clean water. Radiation technology, including electron beams (e-beams) and gamma irradiation, plays a significant role in addressing a wide range of organic pollutants in wastewater and sewage sludge by breaking down these complex molecules into less harmful or more easily removable forms.

Microplastics pose a particularly stubborn challenge because they resist biodegradation and tend to fragment into even smaller particles.

Microplastics have been found in tap and bottled water, the air we breathe, river sediments and soil. They contaminate groundwater and surface water and end up in the ocean. Plastic pollution monitoring carried out under the IAEA’s Nuclear Technology for Controlling Plastic Pollution (NUTEC Plastics) initiative has found microplastics even in the most pristine and protected areas of the planet, including the Galapagos Islands and Antarctica.

Treating wastewater with e-beam technology offers a promising solution. It aggregates microplastics into clumps that can be easily

removed from wastewater. Recent experiments at Poland’s Institute of Nuclear Chemistry and Technology, an IAEA collaborating centre for radiation technology, show that between 85% and 95% of microplastics can be separated from wastewater following treatment with e-beam technology.

“Microplastics are challenging to remove using conventional water and wastewater treatment methods,” said Bumsoo Han, a radiation expert and chief consultant at Bright Future Technologies in the Republic of Korea. “Although research is still in its early stages, ongoing studies are expected to contribute significantly to addressing microplastic pollution in our environment.”

NUTEC Plastics: Addressing plastic pollution

The IAEA’s flagship NUTEC Plastics initiative brings together countries and partners worldwide to address plastic pollution by leveraging nuclear technologies to improve the detection and identification of microplastics and nanoplastics in the marine environment, and to develop effective plastic recycling techniques that reduce reliance on fossil fuel-based plastics. Radiation can be used to make biobased plastics, which are a more sustainable alternative to conventional plastics because they are biodegradable and/or easily recyclable by design.

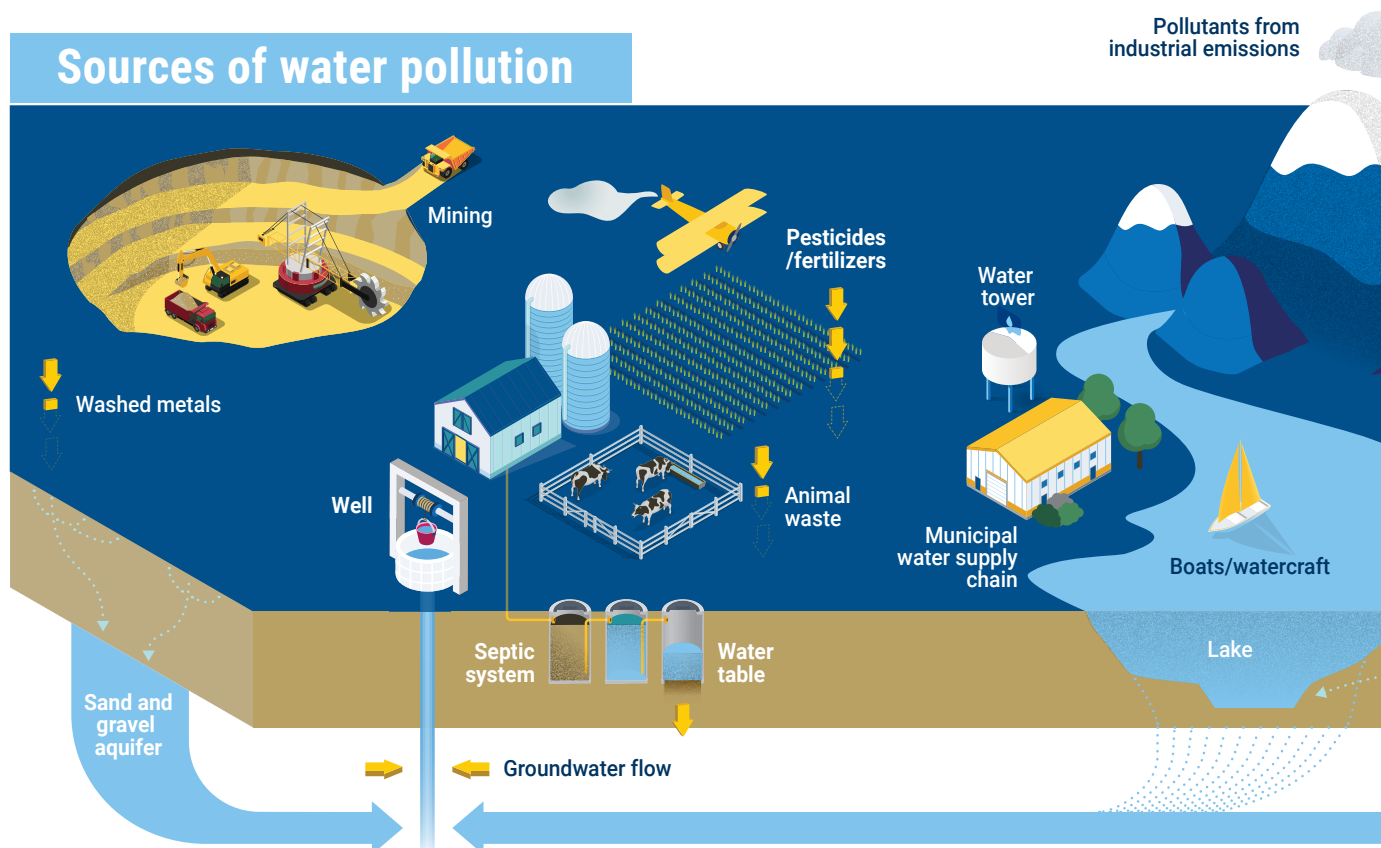
Many countries are keen to move towards a more sustainable plastics economy. At the 2025 United Nations Ocean Conference, where participants focused on the ongoing negotiations towards an international legally binding agreement on plastic pollution, the IAEA highlighted the role of nuclear science in tackling this challenge.

“Nuclear science helps protect our ocean and support life below water,” IAEA Director General Rafael Mariano Grossi said at the conference. “Through our marine laboratories in Monaco and NUTEC Plastics, we are helping countries tackle marine pollution by equipping 100+ labs worldwide to monitor microplastics.”

Around 80% of marine plastic pollution originates on land, so intensifying efforts to improve recycling and treatment of plastic waste before it ends up in landfill sites and water systems would help to address this growing global challenge.

Constructed wetlands to remediate mining wastewater

Natural wetlands — in which freshwater filtering occurs as a result of physical, geochemical and biological processes in soil, sediment and plants — have proved to be effective in sequestering pollutants from contaminated water. Constructed



wetlands — engineered systems that use these same natural processes — are already used around the world to treat wastewater. They are typically less expensive and require less energy to operate and maintain than conventional waste treatment systems.

Constructed wetlands are increasingly being used to remediate water contaminated by mining by-products such as heavy metals and other toxic elements. These can persist for decades after mining has ceased, with potentially serious implications for human health and surrounding ecosystems.

When uranium is mined, naturally occurring radioactive contaminants such as radon and radium are often present in wastewater. According to Hannah Affum, an IAEA industrial technologist, “there is a research gap in how effectively plants and sediments can remove radioactive contaminants in constructed wetlands.”

To help bridge this gap, the IAEA recently launched a coordinated research project that uses radiotracers to investigate how the soil, gravel and plants in constructed wetlands remove and transform contaminants in wastewater produced by uranium, copper and gold mining. As the capacity of constructed wetlands to do this may decrease over time, the project will also investigate flow

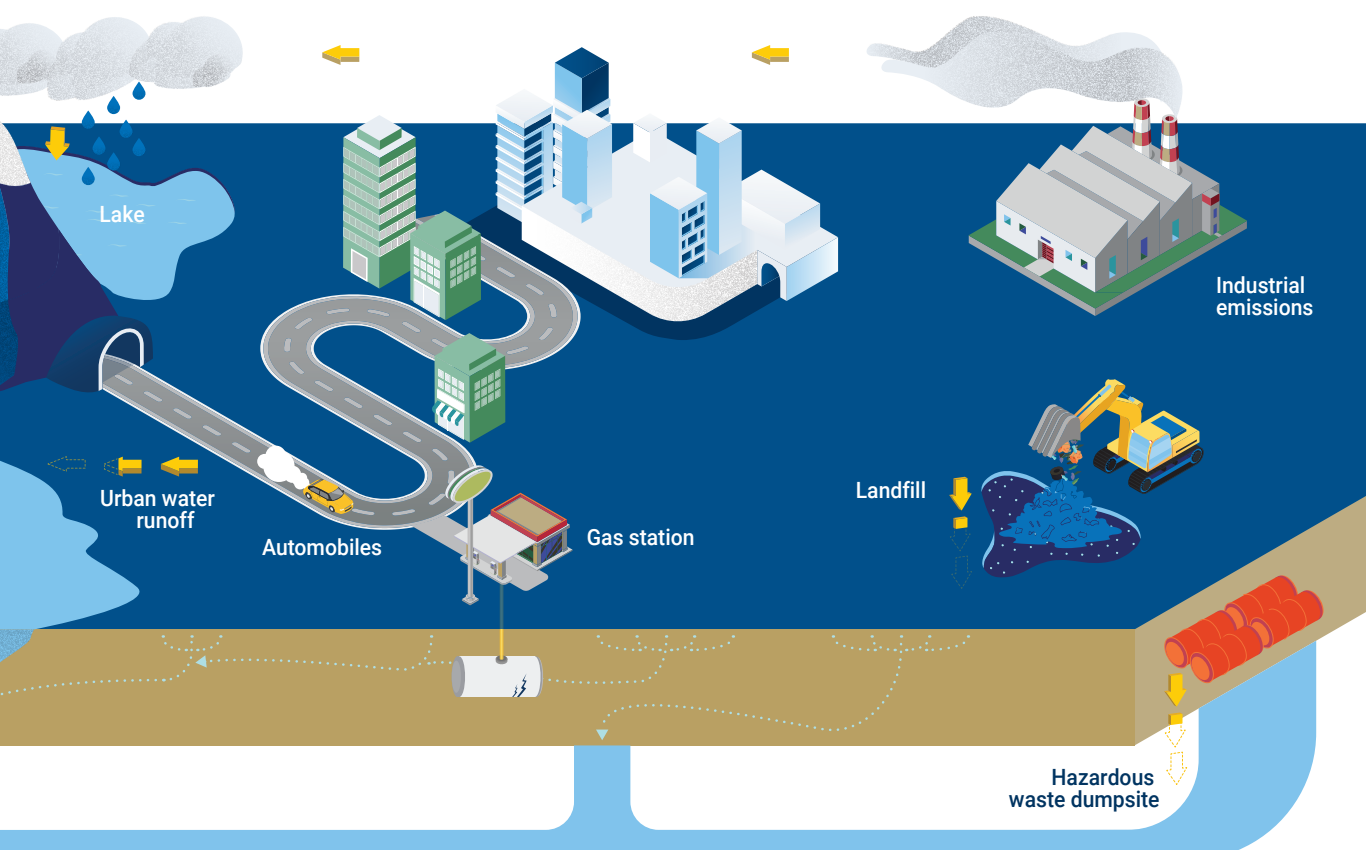


(Photo: AdobeStock)

hydrodynamics and collect data to optimize future wetland designs.

“Focused research can give us critical insights to guide the sustainable design of these systems and improve long term contaminant sequestration,” said Affum.

From nitrogen to compounds of emerging concern, microplastics and heavy metals, the world’s water systems are coming under increasing strain. Nuclear science is providing solutions to meet this challenge.



Infographic: G. Appolinario/IAEA

Understanding the story of a drop of water

Why does it matter?

Does your drinking water come from fresh rain that regularly falls near your city, or from an ancient groundwater reserve in a neighbouring country that's nearing depletion?

Understanding the source and sustainability of our water is crucial to preventing sudden shortages and ensuring long-term access.

With the right data, communities and decision-makers can take informed action. **Isotope hydrology** plays a key role in this process, enabling scientists to trace the origin of water and determine how long it has been circulating since it first fell as rain. This helps us map how water moves through the environment and assess how quickly essential groundwater reserves are being drained.

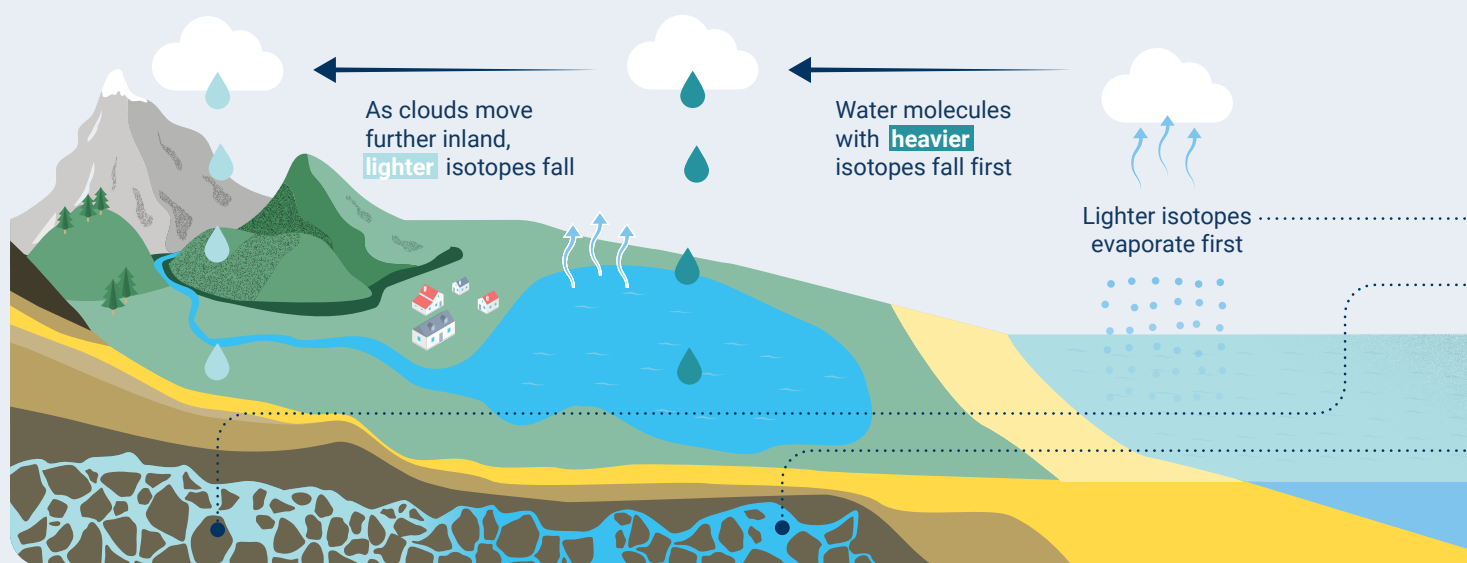
These insights are vital for managing water resources sustainably and protecting them for future generations.



Analysing water samples

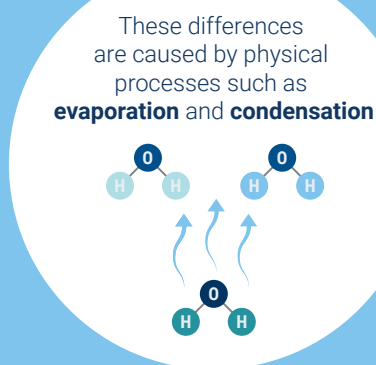
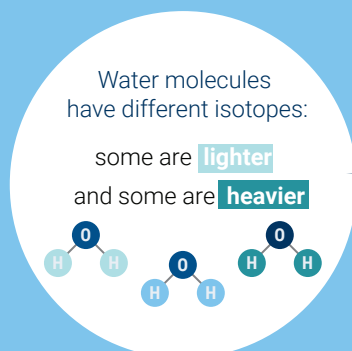
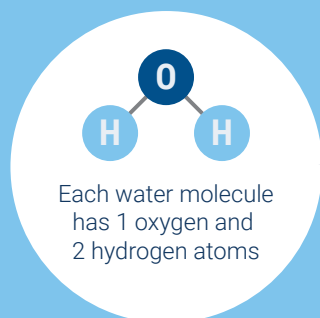
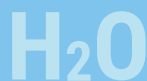
Each water source has a unique **isotopic fingerprint** that reveals its origin, age, quality and rate of renewal.

The IAEA and its partners have been gathering water samples from rain, lakes, rivers, aquifers and other sources around the world for over 60 years. High precision equipment is used to analyse these water samples, obtaining their isotopic composition.



Infographic: G. Appolinario/IAEA

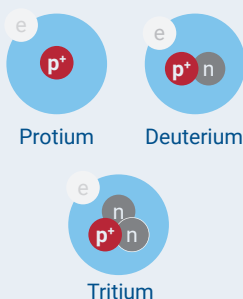
What is a water molecule?



What is an isotope?

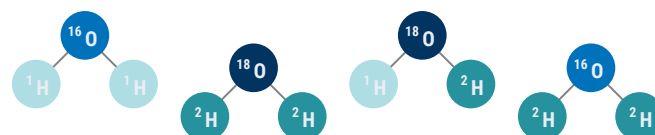
Atoms with the same number of protons (p^+) but different numbers of neutrons (n) are called isotopes.

Take **hydrogen isotopes** as an example:



There are two kinds of isotopes — stable and unstable.

Stable isotopes, like protium and deuterium, have different weights and remain constant over time.



Unstable isotopes, like tritium, are called **radioisotopes**. They change over time and have excess neutrons in their nuclei and emit radiation, which allows their use for **dating water**.

Origin of water

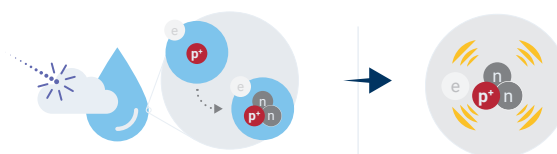
By measuring the ratio between heavy and light isotopes in water from different sources, scientists can determine the **origin and movement of water**.

Direct recharge: groundwater and rainfall have the same isotopic fingerprint.

Mixing: the lake is a mixture of the isotopes in rain and from the river.

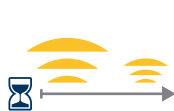
Interaction: groundwater has the same isotopic fingerprint as the lake.

Dating water



Tritium is produced when neutron-rich **cosmic rays** from the atmosphere hit clouds. Tritium has **excess neutrons**, causing it to be **unstable**.

As tritium attempts to become stable, it emits low-level **radiation**.



Radioactive decay follows a predictable pattern in each element.



By analysing tritium's radioactivity, we can tell its age.



Knowing this tells us when this water last fell to the ground as rain.

Brazil's strategy for protecting its freshwater resources

By Emma Atuhaire

Brazil is home to 12% of the world's freshwater, with rivers and wetlands stretching across the Amazon basin. Despite its abundance, water is not a given for everyone. Climate change and human activities are chipping away at this natural resource. With nearly half of Brazil's population relying on these freshwater resources for domestic consumption, agriculture and energy production, protecting them is a national priority.

Investing in scientific innovation

While many countries still rely on conventional hydrological tools such as measuring rainfall or river flows to monitor their water resources, the Geological Survey of Brazil (SGB), an IAEA collaborating centre since 2015, uses sophisticated hydrological and geochemical methods to better understand the country's freshwater systems. The ultimate goal is to improve water quality, fair access, sustainable use and long-term preservation.

The IAEA's water resources programme supported the SGB in identifying key isotope hydrology approaches that would add value to water management strategies. Through this work, the SGB set up an isotope hydrology laboratory, receiving specialized equipment, training and technical support through the IAEA's technical cooperation programme. Until recently, SGB scientists had to send water samples to the IAEA's Isotope Hydrology Laboratory in Vienna for analysis. Thanks to the donation of a portable gas mass spectrometer by Switzerland and

the provision of training by the IAEA, SGB researchers will be able to analyse isotope data on site once the new instrument is installed. The instrument will enable them to study noble gases dissolved in groundwater, which are crucial for estimating the age, origin and flow of water sources and assessing whether they are renewable.

"This pioneering work in several fields of isotopic applications and the increase in technical and analytical capacity have had a major impact on the understanding of water dynamics and, consequently, on the management of resources," said Roberto Kirchheim, a researcher at the SGB's Applied Geoscience Centre.

Brazil is also sharing its knowledge and expertise to support other Latin American countries in strengthening their water management systems. The SGB is ready to play an active role in building a regional network of water laboratories through the IAEA's Global Water Analysis Laboratory Network.

Addressing climate change

Climate change poses a serious threat to Brazil's water resources. According to a 2024 report by Brazil's National Water and Sanitation Agency, some parts of the country could see water resources decrease by more than 40% by 2040.

Brazilian scientists are taking part in several IAEA coordinated research projects to assess the impacts of climate change on water

Two fishermen in a canoe navigating a river in Brazil.

(Photo: AdobeStock)



availability using isotope hydrology. One of these projects identified the Amazon as a key source of rainfall for Brazil and Argentina, which led both countries to strengthen their rainforest conservation efforts.

Through another IAEA coordinated research project, Brazil is studying how freshwater systems respond to the pressures of climate change and human activity to help the country prepare for future climate impacts. The data will inform discussions on groundwater management at both federal and provincial levels, enabling authorities to make evidence based decisions.

Climate-smart agricultural strategies for water resilience

Agriculture, a vital sector for Brazil, is also taking a toll on the country's water resources. Groundwater is often extracted for irrigation at rates that exceed its natural replenishment, threatening long-term water resource management.

To tackle this challenge, Brazil took part in an IAEA coordinated research project that applied isotope techniques to evaluate water sources in irrigation systems. With scientific guidance and coordination from the IAEA, Brazil was able to identify the sources of water used for irrigation, assess how quickly those sources were being naturally replenished, and forecast their future availability.

This knowledge has helped Brazil reduce over-extraction, optimize water allocation and promote climate-smart agricultural practices.

Protecting the Guarani Aquifer

Spanning over 1.2 million square kilometres in Brazil, Argentina, Paraguay and Uruguay, the Guarani Aquifer is the world's second largest transboundary aquifer system, storing over 37 000 cubic kilometres of freshwater. It is especially important for Brazil, where it supplies water for over 14 million people.

Growing water demand, unregulated water use and pollution have raised serious concerns about the aquifer's future. Until recently, the four countries that share it lacked the data to assess how human activity affects the aquifer and how to manage it sustainably. With support from the IAEA's water resources programme, and technology transfer through its technical



cooperation programme, scientists turned to isotope hydrology to study the aquifer's recharge rate, quality and vulnerability to contamination. With this knowledge, the four countries developed joint strategies to manage and protect the Guarani Aquifer for future generations.

"The IAEA's continued support has enabled Brazil to generate unprecedented isotopic datasets on rainfall, rivers, wetlands and deep aquifers, many of which are in data-scarce regions," said Isadora Aumond Kuhn, Coordinator of the National Programme for Isotope Hydrology Applications at the SGB. "This has not only filled critical scientific gaps but also fostered stronger regional collaboration in South America."

The road to COP30

As Brazil prepares to host the 30th United Nations Climate Change Conference (COP30) in November 2025, the country is uniquely positioned to lead the conversation on the urgent need for water governance in the face of climate change and to share its experience with nuclear sciences and international cooperation to drive data-informed decision making. The IAEA, which helped put nuclear solutions on the COP agenda, will showcase how they can contribute to mitigation and adaptation strategies at COP30. This includes building resilience in water systems using nuclear science and technology.

An SGB hydrogeology researcher conducts isotope sampling on part of the Guarani Aquifer system in southern Brazil.

(Photo: R. Kirchheim/SGB)

Scientists study ‘invisible rivers’ to manage extreme weather and water scarcity

By Katrina Vargas

Just as rivers flow across the land, sustaining communities, livelihoods and biodiversity, ‘invisible rivers’ flow above us, carrying more water vapour than all the rivers on Earth combined. These moisture highways — known as atmospheric rivers — have a tremendous impact on weather and rainfall patterns globally.

Climate change and human activities are influencing the behaviour of atmospheric rivers, shifting their paths and causing extreme weather events such as floods, storms and droughts. Studying isotopes in atmospheric rivers can help us understand and track them, thereby improving weather forecasts and predictions of extreme weather events.

What are atmospheric rivers?

Atmospheric rivers are naturally occurring bands of concentrated water vapour thousands of kilometres long that course through the Earth’s atmosphere. They form

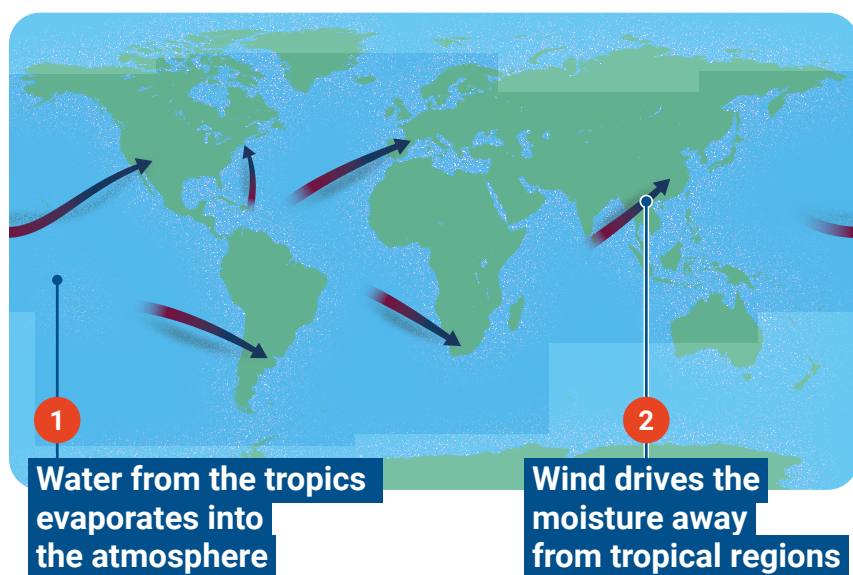
when intense heat from the sun evaporates ocean water along the Equator. Winds carry the water vapour towards the poles, creating ‘rivers in the sky’, which usually flow no higher than 3000 metres above ground — about one third the height of Mount Everest. When they reach coastlines, atmospheric rivers are pushed upwards, and as they approach mountains, they release moisture in the form of rain and snow.

Atmospheric rivers provide vital freshwater to many parts of the world, especially in coastal regions. In California, on the western coast of the United States of America, atmospheric rivers account for about half of annual rainfall, filling reservoirs and supporting farmers. They also account for between 30% and 60% of annual rainfall on the coasts of eastern China, the Korean peninsula and western Japan.

Pressures of climate change

As global temperatures rise, more moisture accumulates in the atmosphere, leading to more intense and frequent precipitation from atmospheric rivers. This phenomenon is responsible for more than 80% of heavy rains in many coastal regions in East Asia.

“As the climate warms, extreme weather events are becoming even more intense, and many are driven by atmospheric rivers,” said Julie Kalansky, Deputy Director of the Center for Western Weather and Water Extremes at the Scripps Institution of Oceanography.



Infographic: G. Appolinario/IAEA

3 As water vapour hits the coasts, it rises over mountains and cools

At the same time, atmospheric rivers are moving away from the Equator and toward the poles. They are becoming less common in subtropical regions, which now face reduced water supply and drought, while places like the Pacific Northwest, Europe and the Arctic are seeing heavier rainfall and flooding.

The role of isotopes

“Atmospheric rivers are highly variable year to year, making it difficult to predict how much rain we’ll get each year,” said Kalansky. “This unpredictability of seasonal precipitation poses major challenges for managing water supplies.”

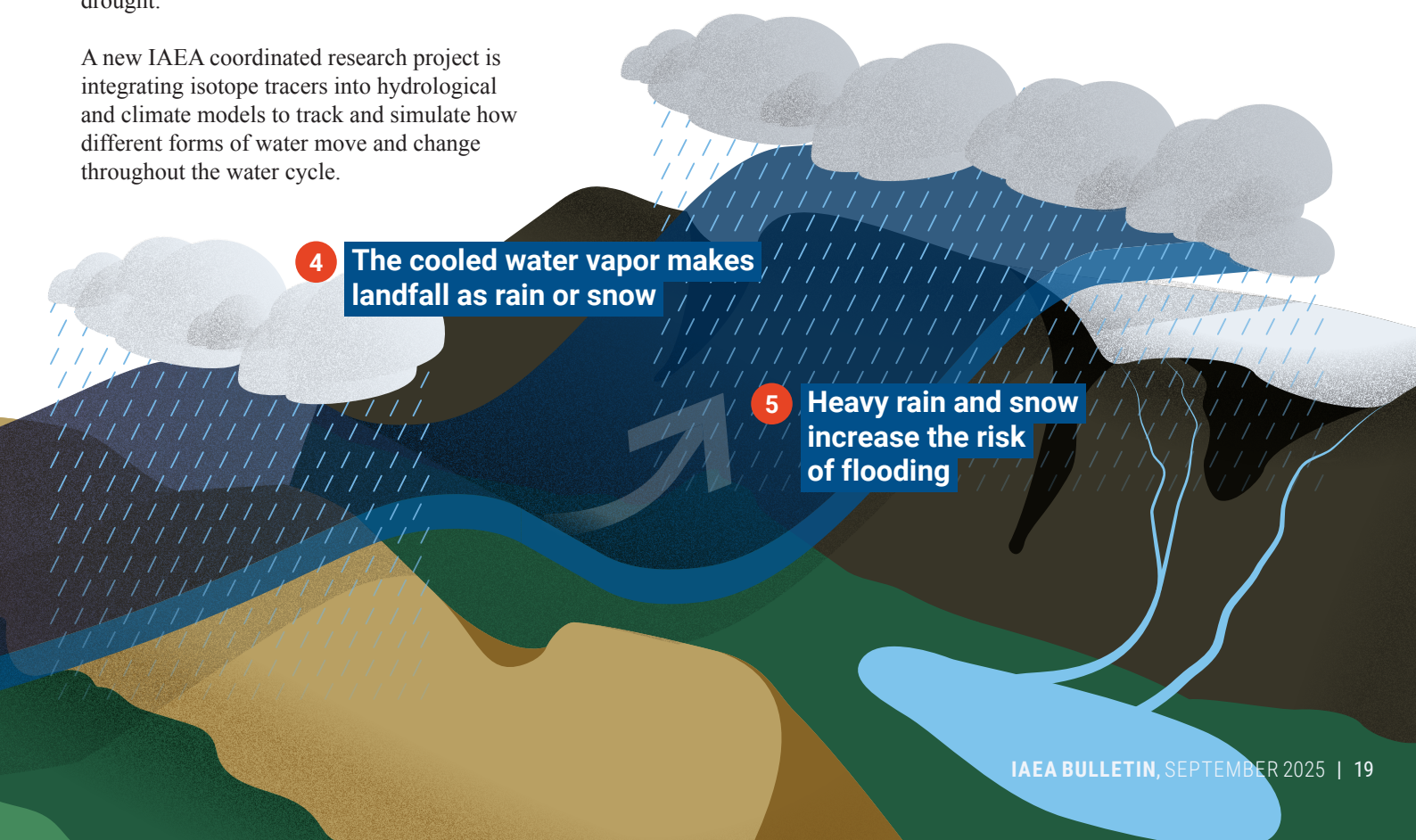
Scientists are using stable isotopes — non-radioactive forms of atoms — to study how climate change impacts atmospheric rivers. The techniques trace where water vapour comes from, how far it has travelled through the atmosphere, where it falls as precipitation and how it interacts with the water cycle. This information can be used to anticipate extreme weather events and reduce their impact, identify flooding risks and manage water resources, especially during drought.

A new IAEA coordinated research project is integrating isotope tracers into hydrological and climate models to track and simulate how different forms of water move and change throughout the water cycle.

“The data we will gather through the research project can help assess the increasing risks of flooding, droughts and water scarcity,” said Jodie Miller, Head of the IAEA’s Isotope Hydrology Section. “It can also help countries develop strategies to mitigate risks, improve water management and enhance climate resilience.”

“We are using data on water vapour isotopes to improve the accuracy of weather forecasts,” said Kei Yoshimura, a professor at the Institute of Industrial Science at the University of Tokyo, who is participating in the project. “Especially useful in mid-latitudes, isotopic data will help better predict moisture transport and rainfall patterns linked to atmospheric rivers.”

The project draws on 65 years of data from the Global Network for Isotopes in Precipitation (GNIP), which tracks precipitation at over 1000 monitoring stations worldwide. GNIP data can be used to analyse the origin, pathways and precipitation patterns of atmospheric rivers, offering insights into their changing behaviour in a warming climate.



4 The cooled water vapor makes landfall as rain or snow

5 Heavy rain and snow increase the risk of flooding

Rethinking irrigation

Improving water use with nuclear science

By Monika Shifotoka

A cosmic ray neutron sensor helps a farmer monitor soil water levels by capturing real-time moisture data, which is displayed on the smartphone in the foreground.

(Photo: M. Casling/IAEA)



Agriculture is the largest global consumer of water, accounting for an average of 70% of freshwater drawn from lakes, rivers and aquifers around the world. The sector places immense stress on water resources, threatening long term water resource management, which is critical for the health of communities, the environment and economies worldwide.

“With growing pressure on water resources, improving water use efficiency in agriculture is no longer optional but essential,” said Mohammad Zaman, Head of the IAEA’s Soil and Water Management and Crop Nutrition Section. “Science based solutions help farmers use every drop wisely while maintaining productivity and sustainability.”

Innovations in nuclear science and related technologies are enabling farmers to adopt climate-smart agricultural practices that save water, boost crop yields and build resilience to climate change.

The IAEA, through the Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture (Joint Centre), provides farmers in water-scarce areas with tools and guidance for smarter irrigation. This enables them to assess the availability of water as well as its movement in soil and uptake by crops, so that they can use it more efficiently.

Supporting efficient irrigation practices

Water, which is composed of one oxygen atom and two hydrogen atoms, contains naturally occurring isotopes (atoms of the same element that have different numbers of neutrons) that are easily traceable. Oxygen isotope-based techniques help scientists understand how plants use water. By analysing the isotopes in water found in soil and within plants, researchers can determine which water sources plants rely on, how much water they use, how much is lost to evaporation and how much percolates into the soil. Understanding these processes allows experts to recommend better irrigation schedules, suitable crop types, and improved farming practices to conserve water and increase yields. This type of information is especially useful in areas facing drought or water scarcity.

Climate-smart agriculture techniques help farmers optimize water use and improve soil conditions, ensuring sustainable agricultural production. The IAEA’s technical cooperation programme has been supporting the adoption of climate-smart agricultural techniques in water-stressed countries in Africa and Asia, including Sudan and Namibia.

Drip irrigation for water conservation in Sudan

Climate change is making weather patterns in Sudan erratic, with dry seasons and unpredictable rainfall causing water shortages, crop failures and food insecurity.

The IAEA has helped hundreds of women farmers in Sudan's Kassala region to grow more food with less water using improved drip irrigation systems, through a pilot initiative under the IAEA's technical cooperation programme. These systems are low cost, easy to install, simple to operate and deliver water directly to plants' roots, minimizing waste. They have enabled Sudanese farmers to reduce water use by up to 70% while boosting crop yields by over 40%. "Thanks to this project, we have seen measurable improvements in water use efficiency," said Ahmed Babiker Khalifa, a water management specialist at Sudan's Agricultural Research Corporation. "Integrating drip irrigation with data from nuclear techniques helps us apply just the right amount of water — a practical solution for farming in water-scarce regions."

The success has inspired broader adoption of the technology in Sudan and beyond, empowered women and helped communities adapt to climate challenges while increasing food security.

Improving harvests in Namibia with cosmic ray neutron sensors

Namibia is one of Africa's driest countries, with 92% of its land classified as arid or semi-arid. In recent years, Namibia has experienced erratic rainfall, floods and severe droughts due to climate change, contributing to serious food shortages.

Since 2020, the IAEA and the Food and Agriculture Organization of the United Nations (FAO), through the Joint Centre, have been training farmers in northern Namibia to water their fields more efficiently.

The farmers are using information derived from a combination of nuclear techniques such as cosmic ray neutron sensors and water-saving irrigation technologies including drip irrigation and rainwater harvesting.

With real-time data on soil moisture collected by cosmic ray neutron sensors and related techniques, farmers can assess available water in the soil. The drip irrigation system helps them to apply precise amounts of water based on plant need.

An IAEA technical cooperation project has enabled farmers to leverage these technologies to reduce water use by 80%. Yields of crops like maize, tomatoes and peppers have also grown by up to 70%.

"Integrating nuclear techniques with smart irrigation practices could revolutionize farmer support," said Maliata Athon Wanga, an agricultural scientific officer in Namibia's Ministry of Agriculture, Water and Land Reform. "Cosmic ray neutron sensors enable data-driven decisions that directly improve water use efficiency, enhancing food security and climate resilience in our communities."

Advanced drip irrigation systems enable farmers to optimize water use, minimize waste and enhance crop yields.

(Photo: N.Jawerth/IAEA)



Decoding water

Advanced tools for understanding water resources

By Thomas Perrouy

From glacial melt to precipitation patterns and evaporation rates, IAEA isotope hydrologists are collecting, analysing and sharing data to better understand the sources, history and movement of water. New tools and methods allow researchers to analyse water data more precisely than ever, providing critical information for effective water resource management, climate modelling and environmental policymaking.

“Water data are the backbone of smart policy and informed investments,” said Celeste Saulo, Secretary-General of the World Meteorological Organization. “Without data we are blind. Early warning systems for floods and droughts as well as the design of water infrastructure such as reservoirs, irrigation schemes and drainage systems depend on data. Isotope hydrology adds a unique lens — tracing water sources and flow paths to help us manage shared water resources sustainably.”

Artificial intelligence

As global water data networks expand, isotope hydrology is rapidly advancing into the realm of big data. Artificial intelligence (AI) and machine learning models are revealing new insights in water research, improving predictions and filling data gaps.

An IAEA study that used AI to analyse isotopic data from 1257 lakes in 91 countries revealed that about 20% of their water

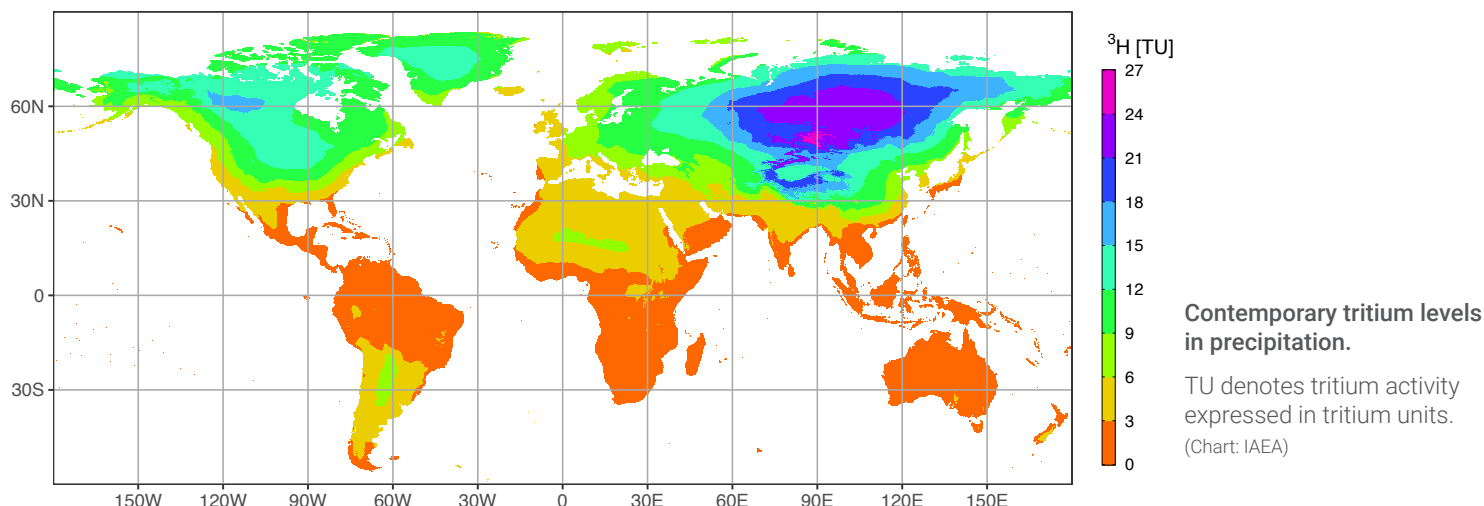
inflow is lost to evaporation, and in about 10% of cases, the lakes show extreme evaporation losses of more than 40% of total inflow. This means that many lakes cannot compensate for evaporation, which puts them at risk of disappearing over time. “We used artificial intelligence to determine the main evaporation drivers,” said Yuliya Vystavna, an IAEA isotope hydrologist and the study’s first author. “Depending on climate type — tropical, arid, temperate, continental or cold — evaporation is driven by different factors.” The study used AI models to determine which lakes were at greatest risk of disappearing.

Another IAEA study used machine learning models to identify factors influencing water dynamics and estimate the ‘young water fraction’ — water less than three months old — in 45 river basins around the world. The young water fraction reflects how water is stored and released in the environment, revealing patterns of retention and flow. This helps to increase understanding of how rivers react to weather and land changes, enabling communities to better prepare for floods and droughts and manage their water resources more effectively. “By understanding these dynamics, we can better adapt to the challenges posed by a changing climate and evolving land use patterns, ensuring that rivers continue to provide their essential services to ecosystems and human societies,” said Tzanka Kokalova-Wheldon, Director of the IAEA Division of Physical and Chemical Sciences.

A recent IAEA analysis showed that many lakes around the world are unable to compensate for evaporation and are at risk of disappearing over time.

(Photo: Y. Vystavna/IAEA)





Experts believe that using AI and machine learning to analyse water data has the potential to significantly improve decision-making processes for sustainable water management. To advance this effort, the IAEA, the United Nations Educational, Scientific and Cultural Organization and the International Centre for Theoretical Physics recently developed a framework for integrating AI with hydrological and isotopic data.

High resolution tritium mapping

Tritium, a naturally occurring radioactive isotope of hydrogen that is present in water and has a half-life of about 12.3 years, is valuable for identifying recently replenished groundwater and assessing its vulnerability to pollution. By mapping where this trackable form of hydrogen appears in rain and snow, researchers can gain insight into recent water movements and sources. Using data collected over the last decade, the IAEA has developed maps of tritium distribution in precipitation to optimize sampling, identify atmospheric data gaps and support research on aquifer vulnerability.

Scientists use the maps to compare tritium levels in precipitation and groundwater to understand how quickly precipitation reaches and interacts with aquifers. When groundwater tritium closely matches rainfall tritium, this may signal rapid recharge, meaning that the aquifer is well supplied but also vulnerable to pollution, since pollutants can easily follow the same path. When groundwater contains much less tritium than local rainfall, this may indicate that the water has been safely stored underground and protected from contamination for decades or longer.

Nitrous oxide laser spectrometry

Nitrous oxide laser spectrometry is a new technique that provides highly precise measurements of isotopes related to nitrogen cycling (the movement of nitrogen between air, soil, water and organisms), which can be used to trace pollution sources. Because different nitrogen sources (such as the burning of fossil fuels, agricultural emissions and natural processes) have distinct isotopic signatures, scientists can identify and differentiate between human-caused and natural contamination sources. In India, for instance, where fertilizer use has tripled in 30 years, IAEA scientists used the technique to study agriculture's impact on water systems. Their findings showed that nitrate pollution spikes during the monsoon season when heavy rains wash fertilizers into rivers and lakes, worsening water quality. By tracking isotopes, scientists can pinpoint the sources of this pollution, which may encourage farmers and governments to adopt cleaner practices to improve both water and air quality.

As technological capabilities and data collection methods continue to advance, the IAEA is proactively exploring new tools and approaches for water data analysis to support sustainable water management strategies. "By combining cutting-edge technology with decades of water data collected across the globe, we're not just studying water, we're empowering countries to make informed decisions about their most precious resource," said Stefan Terzer-Wassmuth, an IAEA geospatial data expert.

Transboundary water cooperation creates a ripple effect in South East Europe

By Mary Albon

Bosnia and Herzegovina and Montenegro are part of the Dinaric karst, a region of impressive limestone mountains and countless caves, sinkholes, springs and underground streams that stretches along the Adriatic coast.

Karst is a complex geological environment shaped by water, which corrodes and dissolves the soft stone. Because limestone is porous, surface water does not collect in karst landscapes — instead, it seeps down through the rock to form aquifers.

Bosnia and Herzegovina and Montenegro share the Oko-Bijela Gora karst aquifer, which spans the border between the two countries and covers some 1800 square kilometres. Karst aquifers are key to sustaining the natural environment and are an important source of drinking water and water for agriculture, industry and electricity generation. More than a quarter of the world's population depends on water from karst aquifers. However, their porosity makes them vulnerable to contamination and the impacts of climate change.

Using isotopes to decode karst aquifers

Until recently, neither country had a good understanding of the aquifer's hydrological conditions. In 2020, both countries joined 25 others across Europe and Central Asia in participating in an IAEA regional technical cooperation project to study how climate change influences groundwater resources. The project aimed to train water specialists in the latest techniques for water sampling and analysis, calculating recharge rates and developing models for regional water cycles. Through fellowships, scientific visits and a regional meeting, participants deepened their knowledge of climate change scenarios and formed a regional network of experts with the skills and equipment to monitor and evaluate water resources using isotope hydrology.

Hydrologists from Bosnia and Herzegovina and Montenegro worked together to develop the first conceptual model of the Oko-Bijela Gora karst aquifer. The IAEA provided equipment and supplies for fieldwork and laboratory analysis and training in isotope analysis. The scientists collected precipitation, groundwater and surface water samples and used their newly acquired skills in isotopic analysis to study factors affecting the aquifer's sustainability, including as a source of drinking water and for hydropower generation.

Combining these findings with historical hydrological and meteorological data, the researchers determined the conditions for the aquifer's recharge. With this new knowledge, they developed models and maps to identify groundwater recharge areas and explored how surface water affects the aquifer's hydrogeological cycle. This information provides a blueprint for a water resource management policy that could help both countries protect their shared aquifer.

“The implementation of this project has set a clear direction for guiding the design of future research in the field of water research management and climate change,” said Uroš Jurošević, Head of the Department for Geographic Information Systems at the Geological Survey of the Republic of Srpska in Bosnia and Herzegovina.

The project was the first to use isotopic techniques to investigate transboundary groundwater and surface water management in the region. It demonstrated that isotope hydrology is an important tool for studying karst aquifers.

“Working together with colleagues from the region strengthens mutual understanding and supports the sustainable management of this vulnerable karst system,” said Dragan Radojević, Head of the Department for Hydrogeology and Geotechnical Investigations at the Geological Survey of Montenegro.



Cooperating across borders

Over 150 countries share transboundary water resources, which account for 60% of global freshwater flows.

The experience of Bosnia and Herzegovina and Montenegro, as well as other participants in the IAEA project, showed that regional cooperation is fundamental to the resilience and sustainability of transboundary water systems in a changing climate.

“Cooperation on shared water resources can improve water management. It can also pave the way for cooperation in other sectors,” said Najat Mokhtar, IAEA Deputy Director General and Head of the Department of Nuclear Sciences and Applications.

Bosnia and Herzegovina and Montenegro are continuing their joint work on the Oko-Bijela Gora karst aquifer through a new IAEA regional technical cooperation project to enhance national isotope hydrology capacities and support evidence based water management.

“The aim is to translate scientific knowledge into practical policy that strengthens water management, which is especially important for shared water resources and in light of climate change,” said Sibel Unlu, an IAEA technical cooperation programme management officer. “Improved transboundary water management, in turn, strengthens water resource management.”

Collecting water samples at a temporary spring fed by the Oko-Bijela Gora karst aquifer.

(Photo: B. Jolović)

Nuclear and isotopic solutions for water scarcity

Focus on Africa and West Asia

By Joelle Matta



Fresh groundwater samples from the North Kuwait aquifer are collected for isotopic analysis by the Kuwait Institute for Scientific Research (KISR).

(Photo: KISR)

In arid northern Kuwait, scientists lower a sampling tube deep into a dry well to reach the shallow pool of groundwater at its bottom. The water, which has been hidden underground for thousands of years, is being analysed as part of an IAEA research project on the country's limited natural freshwater resources. The team is using isotopic analysis to study how carbon dioxide levels affect rainwater and groundwater and to better understand changes in water quality.

Groundwater is a scant resource in many parts of Africa and West Asia. Dwindling rainfall, rising temperatures and growing demand are increasing the pressure on the regions' aquifers. Supported by the IAEA, countries are deploying isotope hydrology — a nuclear technique that traces the source, age and movement of water — to manage groundwater supplies more sustainably.

Isotope hydrology “gives us a fingerprint of the water molecule,” said Jodie Miller, Head of the IAEA's Isotope Hydrology Section. “Using that fingerprint allows us to evaluate how long ago water in the ground fell as precipitation.”

Nuclear technology to assess groundwater contamination

As part of a recent IAEA coordinated research project, Kuwait, together with Algeria, Morocco and Tunisia, used noble gas isotopes such as helium-4 and krypton-81 to date deep fossil water — ancient groundwater that has remained underground for thousands of years with little to no current recharge — and assess potential contamination from nearby petroleum activity. The research helped determine whether the groundwater was safe for sustained use, a critical step in long term water planning.

“Studies using noble gases and radiocarbon have identified groundwater in Kuwait that is approximately 36 000 years old,” said Chidambaram Sabarathinam, a research scientist at the Kuwait Institute for Scientific Research (KISR). “This information helps us identify periods of intense recharge and supports long term planning to sustainably manage these non-renewable water sources.”

In the North-Western Sahara aquifer system — which extends over one million square kilometres and is shared by Algeria, Libya and Tunisia — the use of noble gases such as krypton-81 has revealed that much of the groundwater is over 150 000 years old. Countries are taking coordinated steps to protect one of the region's most important shared water resources and ensure that the water is used carefully and preserved for generations to come.

In Kuwait, where almost all drinking water is produced through desalination, natural groundwater remains a vital reserve, especially during emergencies or supply interruption. Noble gases and stable isotopes have been used to test groundwater for fugitive gas contamination from the country's oil fields. Since 2000, the IAEA has supported capacity building for isotope hydrology and water resource management

through its technical cooperation programme, including by helping KISR establish a laboratory to conduct analysis on isotopes and carry out groundwater surveys.

Managing limited water resources

In Tunisia, groundwater supports much of the country's agriculture. Reduced rainfall and increased demand are stretching groundwater reserves. Tunisia is responding by managing aquifer recharge — the process of storing surplus surface water underground for use during dry periods. The IAEA is working with Tunisian scientists on the use of isotopes to trace how long recharged water remains underground and how far it travels from the recharge site.

“Environmental isotopes play a crucial role in Tunisian groundwater resource management,” said Kamel Zouari, Professor and Laboratory Head at the National Engineering School of Sfax, Tunisia. “These isotopic techniques are particularly effective for assessing complex multilayer aquifer systems, especially in hyper-arid areas.”

Building local capacity

Integrating groundwater into water management strategies is critical in Djibouti, a country with little surface water and frequent drought. In 2023, with support from the IAEA technical cooperation programme, Djibouti opened its first national isotope hydrology laboratory. The facility has modernized the analysis of water samples, improving the country's ability to protect water supplies and manage drought. The laboratory's success is a model for other capacity-building efforts in the region.

Monitoring water quality

Isotope hydrology is also helping countries assess the quality of their groundwater. In Morocco and Tunisia, isotope techniques

are used to trace the sources and pathways of nitrate contamination in groundwater, particularly from agricultural runoff and urban wastewater. In Jordan, isotopes are used to determine natural radioactivity in deep groundwater and inform decision making about the safety of drinking water.

Filling a critical gap

As water scarcity increases in Africa and West Asia, the call for science based water management grows more urgent. With IAEA support, countries across the region are establishing training programmes and laboratories, and accumulating the tools and expertise needed to make well informed decisions about how and when to use their water. These activities are part of IAEA regional technical cooperation projects to support sustainable water use in arid regions.

“The use of nuclear techniques in water resource management helps communities work towards more sustainable water resources, one drop at a time, which in turn can play a role in boosting economic development,” said Hua Liu, IAEA Deputy Director General and Head of the Department of Technical Cooperation.

Collecting rainwater samples in Djibouti for isotopic analysis using equipment provided by the IAEA.

(Photo: Y. Vystavna/IAEA)



A day in the life of an IAEA isotope hydrologist

By Wolfgang Picot



What we do supports so many areas – agriculture, climate change, public health and more. I am proud to be part of it.

– Stephen Wangari,
IAEA Isotope Hydrology
Laboratory

On a sunny spring morning, Stephen Wangari joins other young scientists from the IAEA's Isotope Hydrology Laboratory carrying pumps, vials, plastic containers and tubes to a quiet backwater of the Danube River near the IAEA Headquarters in Vienna. On the grassy bank, they connect the equipment, submerge a tube in the water and turn on a pump. Water starts circulating through the set-up, which the scientists closely monitor.

"This is a test run to improve water sampling," says Astrid Harjung, a researcher in the laboratory. "It doesn't look very fancy, does it?" she laughs, pointing at the items spread out on the grass. "But field tests like this give us a chance to test and fine-tune the equipment under real conditions so that sampling can be done as efficiently as possible."

Tracking surface water migration with sulphur-35

Astrid and her team are developing a new method that utilizes sulphur-35 to track how surface water — and any contaminants it may carry — migrate into groundwater.

"Sulphur-35 has a short half-life of 87 days and occurs naturally in precipitation," Astrid explains. "Tracing it helps us quickly assess whether groundwater in a specific location is vulnerable to contamination. This could be especially useful, for example, in refugee camps without proper sanitation or in areas affected by natural disasters."

Stephen assisted in the initial development of sulphur-35 analysis while an intern in the laboratory. After a stint at a laboratory in his home country of Kenya, he is now back at the IAEA as a technician in the Isotope Hydrology Laboratory, where the focus of his work has shifted from sulphur-35 to tritium.

Understanding the water cycle

Tritium is an isotope of hydrogen with a half-life of 12.3 years, providing water cycle information over a timeframe of around 50 years. This information helps hydrologists and water managers understand longer term changes in groundwater recharge, how well aquifers are connected to surface water systems, and what this means for groundwater sustainability.

Supporting Member States with tritium analysis has been a core function of the Isotope Hydrology Laboratory for over 60 years.



As Stephen's colleagues continue their work on the riverbank, he says a quick goodbye and heads off to the laboratory to process water samples for the Global Network of Isotopes in Precipitation.

He checks for new water samples from Member States and finds that several have arrived. His day will be spent purifying, enriching and measuring them.

How tritium analysis works

Stephen puts each sample in a water purification system. He connects tubes that will guide the water through tiny columns filled with ion exchange resins — special materials that act like magnets on salts and other charged particles, removing them from the water. The process takes about an hour, and Stephen uses the time to update the laboratory's sample database.

Once the water purification is done, the samples are ready for the next step: enrichment. Stephen inserts them into the electrolytic enrichment system, a two-metre-long, steel framed machine lined with cables, digital displays and rows of tubes. Electricity begins to flow through the system.

Unlike sulphur-35, which floats freely in water, tritium is part of the water molecule itself, so it cannot simply be filtered out for measurement. Electrolysis gradually splits water molecules into hydrogen and oxygen gases, reducing the water's volume and consequently concentrating the tritium.

Stephen regularly checks and maintains the machines and oversees the enrichment process, which can take up to two weeks to complete. He ensures that the electricity running through the samples is gradually increased as required.

“We are always striving to improve the enrichment process,” he says. “The concentration of tritium is very low and hard to measure. Effective enrichment is essential in getting reliable information out of the samples.”

Although tritium is highly concentrated after the enrichment process, it is still barely detectable in water samples. Even the faintest contamination from atmospheric radiation could distort the measurements of the samples. That is why Stephen takes the enriched samples to a room located several stories underground and lined with thick concrete, shielding it from environmental radiation. Here, he carefully mixes each sample with a chemical solution and puts them into machines that will measure their radioactive signature over the next 24 hours.

Back upstairs, the day is drawing to a close. Astrid has returned from the field and she and Stephen catch up. They are happy with the progress they have made and discuss their tasks for the following day.

“Our work here connects us with many regions of the world,” Stephen says, as he hangs up his lab coat and prepares to head home. “What we do supports so many areas — agriculture, climate change, public health and more. I am proud to be part of it.”



(Photos: A. Barber Huescar/IAEA)

IAEA networks promote water research

Clean, accessible freshwater accounts for only 0.5% of Earth's water resources, and this limited supply is under stress from pollution, climate change and the increasing demands of a growing global population. Yet many countries lack crucial data on their freshwater resources, hindering their ability to manage them.

For over six decades, the IAEA has helped countries track and manage their water resources by collecting data and building global networks that improve how water data are shared and used. These networks foster collaboration and innovation in water research and water resource management.

GNIP and GNIR data are available through the WISER portal



Scan to access
WISER portal

The **Global Network of Isotopes in Precipitation (GNIP)**, established by the IAEA and the World Meteorological Organization in 1960, provides data that help countries understand and track shifts in precipitation patterns and identify which precipitation events — rainstorms, hurricanes, snowfall — are of key importance for groundwater recharge. Now in its 65th year, GNIP has compiled over 150 000 monthly records from 1200 sites in over 100 countries. “Through our partnership with the IAEA,” said WMO Secretary-General Celeste Saulo, “we’re deepening the scientific foundations of water cycle understanding, expanding open data, and unlocking innovations that drive better decisions in an era of climate change and growing water stress. We cannot manage what we do not

measure. Data exchange is therefore critical, and this depends on trust and collaboration.”

The **Global Network of Isotopes in Rivers (GNIR)**, launched by the IAEA in 2002, provides river water data to assess freshwater inflows and outflows, evaluate human impacts on rivers, quantify interactions between groundwater and surface water, and identify the effects of land use changes on rivers and streams. These data help us to understand how rivers are responding to climate change and to ensure their future resilience.

The IAEA is also developing a **Global Network of Isotopes in Lakes (GNIL)** to monitor how lakes respond to climate change, in particular evaporative loss.

IAEA by the Numbers

The IAEA is working to increase water cooperation through its **Global Water Analysis Laboratory (GloWAL) Network**. Launched in 2023, the network aims to give countries the tools and expertise to measure, monitor and manage their water resources effectively.

“The GloWAL Network exemplifies the IAEA’s dedication to empowering countries, encouraging collaboration, producing data for policymaking and promoting water’s essential contribution to peace and prosperity,” said IAEA Director General Rafael Mariano Grossi.

In its first 5 years, the GloWAL Network plans to create 7 regional laboratory networks, equip 100 laboratories, train 1000 water experts, and generate at least half a million data points that will be fed into a global database accessible to scientists and policymakers worldwide.

Scan to learn more about the
GloWAL Network



(Photo: AdobeStock)

More than 2 billion people live in countries under water stress. Of the 120 countries with water quality data, only 71 have information about groundwater. By 2030 the health and livelihoods of 4.8 billion people could be at risk if water quality monitoring is not improved.

105 Member States are working with the IAEA on **isotope hydrology** to improve **water resource management**

(since 2020)

91 research projects in 54 countries are supported by the IAEA through its **Coordinated Research Programme**

(as of July 2025)

485 scientists in 118 countries have been trained in **isotope hydrology**

(since 2020)

53 Member States use **isotope hydrology** for **transboundary water resource assessment**

102 Member States contribute data to the **Global Network of Isotopes in Precipitation**

IAEA and World Bank join forces to strengthen water security in Niger



IAEA Director General Rafael Mariano Grossi and Niger's Minister of Hydraulics, Sanitation and Environment, Maizama Abdoulaye, sign an agreement supported by World Bank funding to improve water security in the country.

(Photo: D. Candano Laris/IAEA)

The IAEA and Niger have signed an agreement, backed by World Bank funding, to improve water security in the country. This landmark collaboration will strengthen water resource management by building a national water quality laboratory and modernizing regional water laboratories in the country.

“With water scarcity affecting lives and livelihoods, strengthening Niger’s water management is critical,” said IAEA Director General Rafael Mariano Grossi. “With this agreement, we are providing the country with the infrastructure, tools and expertise it needs to better manage this precious resource.”

“Niger can count on the IAEA to strengthen its water management

capabilities and build long term resilience on this front,” Grossi said.

The agreement was signed on 13 March 2025 in Niamey by the IAEA Director General and Niger’s Minister of Hydraulics, Sanitation and Environment, Maizama Abdoulaye, in the presence of Han Fraeters, World Bank Country Manager for Niger.

Niger faces severe water scarcity due to its arid climate, rapid population growth and limited water infrastructure, and has growing concerns regarding water quality.

The modernization of Niger’s regional water laboratories “is more vital than ever,” according to Minister Abdoulaye. “It is a question of speeding up the action to be taken, to

warn the population of contamination risks and protect them against these chemical threats. I am delighted to sign this agreement with the IAEA, which will establish a reference laboratory and upgrade existing ones.”

Water security — the availability, quality, management and protection of water — is essential for human development and environmental and economic sustainability. The IAEA helps countries to manage their freshwater resources using isotope hydrology, a nuclear technique that provides information about reserves of surface water and groundwater — including water origin, movement and quality — and the interactions between them. The IAEA provides critical support to countries working to determine the age of their groundwater

reserves to ensure that they can be managed sustainably.

Once operational, Niger's new national water quality laboratory will assist the country in evaluating the distribution, replenishment and quality of its water resources to support the economic development of the country needed for its growing population. The laboratory is part of a larger project to develop an integrated water resource platform

to strengthen water-related planning, policies and investment.

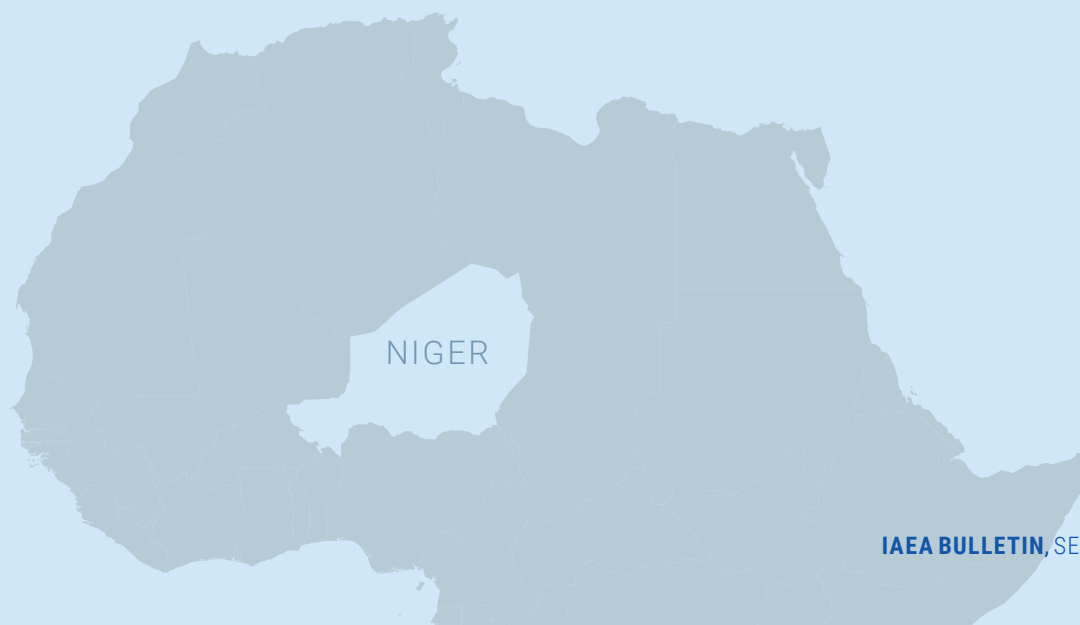
The new partnership builds on commitments made during the United Nations 2023 Water Conference in New York. At a side event launching the Global Water Analysis Laboratory (GloWAL) Network, the IAEA and Niger pledged to work together within the GloWAL Network, with support from the World Bank.

The agreement's primary objective is to ensure that Niger's new national water quality laboratory is fully operational, properly equipped and staffed with skilled analytical technicians. The IAEA will work closely with Niger to develop the laboratory with a strong focus on long term sustainability.

— By Thomas Perrouy



The new collaboration will strengthen water resource management by building a national water quality laboratory and modernizing regional water laboratories in Niger. (Photo: D. Candano Laris/IAEA)



Nuclear desalination: A sustainable solution for water security in the Arab region



(Photo: AdobeStock)

Nuclear desalination is offering countries in the Arab region and beyond a clean alternative to energy-hungry traditional desalination.

Freshwater scarcity is a persistent challenge in the Arab region, where limited natural water resources and rapid population growth are placing an increasing strain on supply. For decades, countries in the region have relied on traditional desalination, which depends heavily on fossil fuels. With growing energy demands and climate change concerns, many countries are now exploring the cleaner alternative.

By using nuclear energy to power the desalination process, countries can reduce greenhouse gas emissions while producing a steady supply of fresh water.

With the support of the IAEA, several Arab countries are assessing the feasibility of nuclear desalination through technical studies, training programmes and regional cooperation. As interest in the technology grows, it is increasingly seen not only as a practical solution, but also as part of a broader strategy to enhance water security amid complex development and environmental challenges.

How the IAEA supports nuclear desalination

The IAEA has been working with Arab countries for almost 30 years to support nuclear desalination initiatives. Through feasibility studies, training programmes and research, the IAEA helps countries explore how nuclear energy can support freshwater production. Specialized tools such as

the Desalination Economic Evaluation Program (DEEP) enable decision makers to compare costs and efficiency across different technologies.

Unlike conventional desalination, nuclear desalination uses reactor-generated heat and electricity to separate salt from seawater, reducing carbon emissions while providing a stable, long term water source.

JORDAN

Advancing SMR-powered desalination

Jordan, where 75% of the territory is classified as arid desert, is taking significant steps towards nuclear desalination. The Government is exploring the use of small modular reactors (SMRs) to power desalination plants.

“Desalination is considered the primary source of freshwater in Jordan to fulfil the expected demand and reduce the supply–demand deficit,” said Khalid Khasawneh, Commissioner for Nuclear Power Reactors at the Jordan Atomic Energy Commission (JAEC). “It offers competitive prices for freshwater to end consumers, in comparison with imported energy sources.”

SAUDI ARABIA

The desalination leader explores nuclear

Saudi Arabia, already the world’s largest producer of desalinated water, began exploring the use of nuclear energy for desalination in the 1970s. As part of its strategy to move from an oil-based economy towards diversified power production, the country is now considering nuclear power plants to achieve its net zero ambitions and meet its long term water needs.

According to the King Abdullah City for Atomic and Renewable Energy, “the Kingdom is planning a sustainable energy mix that includes atomic energy to meet the energy needs of the Kingdom to produce electricity, desalinated water and thermal energy” with the aim of reducing reliance on hydrocarbons and supporting economic growth.

EGYPT

Nuclear power and water strategy

Egypt is also integrating nuclear technology into its water strategy. With the country’s first nuclear

power plant, El-Dabaa, under construction, discussions are under way about pairing nuclear energy with desalination in coastal regions. According to the Egyptian State Information Service, “nuclear facilities can supply the energy required for desalination plants to produce potable water.”

KUWAIT

Exploring nuclear desalination for sustainable water solutions

Kuwait, which depends heavily on seawater desalination to meet its freshwater needs, is increasingly turning to nuclear technologies to find more sustainable solutions. “Kuwait is facing the effects of climate change, ocean acidification, and pollution from the oil and shipping industry and power and desalination activities,” said Nader Al-Awadi, Executive Commissioner for International Cooperation at the Kuwait Institute for Scientific Research. In line with its efforts to address these environmental challenges, Kuwait has established a large-scale facility to conduct research into ocean acidification in order to increase understanding of the impacts of changing ocean conditions on marine ecosystems, which are directly tied to the effectiveness of desalination technologies.

Future prospects

Nuclear desalination requires investment, regulatory frameworks and stakeholder engagement. The IAEA is working closely with interested governments to advance

the safe, efficient and cost-effective implementation of the technology.

Continued investment, knowledge sharing and regional partnerships between Arab countries exploring nuclear desalination will be key to its success. If widely adopted, nuclear desalination could increase water security in the region for generations to come. Highlighting this growing engagement, Khasawneh of the JAEC stated: “IAEA support for Jordan’s nuclear programme, particularly the SMR project, is highly valued and plays a pivotal role in enhancing our capabilities and advancing our endeavours.”

“Non-electric applications powered by nuclear energy, such as desalination, present sustainable solutions for a number of water-intensive endeavours — from the consumption needs of millions of households and the industrial applications of freshwater, to agriculture and livestock rearing,” said Francesco Ganda, the IAEA’s Technical Lead for Nuclear Non-Electric Applications.

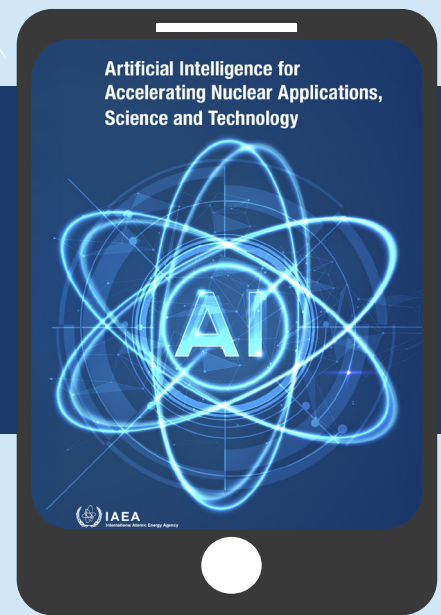
— *By Joelle Matta*

Did you know

that water resource management is being improved by harnessing the power of AI?

Scan to read

how AI is advancing the peaceful uses of nuclear sciences in the water sector.



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