Abstract

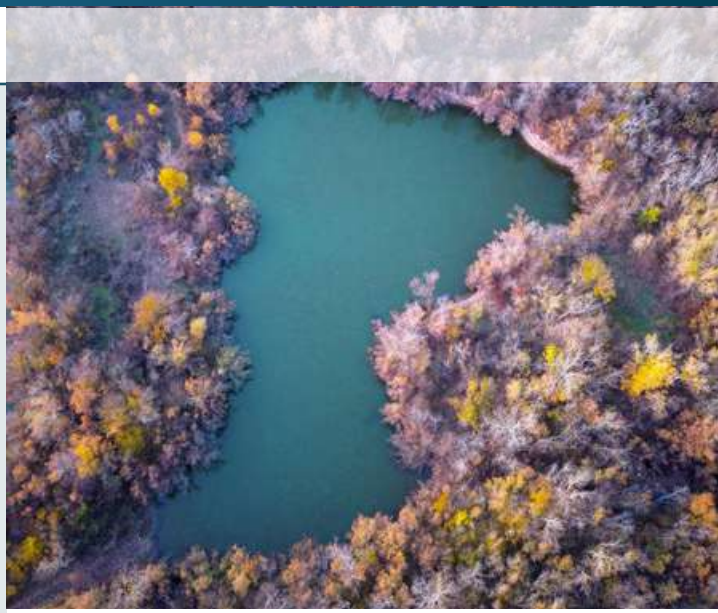
Groundwater is a cornerstone of global water security, yet increasing pressures from overextraction, climate change, and contamination threaten its longterm sustainability. Managed Aquifer Recharge (MAR) offers a powerful naturebased solution to enhance groundwater availability while supporting circular water economies through the reuse of unconventional water sources. However, the growing presence of highly persistent and mobile contaminants of emerging concern (CECs)—including PFAS, pharmaceuticals, pesticides, and industrial organics—poses significant risks to MAR operations. AQUICIRC addresses this challenge by developing innovative, safe, and optimized MAR strategies across six diverse case study sites in Europe and Africa.

AQUICIRC brings together leading institutions from Tunisia, Italy, Spain, the Netherlands, Belgium, and South Africa to advance the scientific, technological, and operational foundations of MAR. The project integrates field monitoring, analytical chemistry, laboratory experiments, and advanced hydrogeological and reactive transport modelling to evaluate the fate and transport of CECs in aquifers recharged with treated wastewater, industrial effluents, and harvested rainwater. By comparing MAR systems ranging from infiltration basins and check dams to subsurface irrigation and direct injection, AQUICIRC generates crossregional insights into how hydrogeological settings, climate conditions, and recharge strategies influence water quality outcomes.

A key innovation of AQUICIRC lies in enhancing MAR treatment performance through permeable reactive materials and naturebased pretreatment systems, alongside the deployment of lowcost Internet of Things (IoT) sensors for realtime groundwater quality and level monitoring. These technologies will feed into predictive modelling frameworks that optimize MAR design for improved contaminant attenuation, increased storage efficiency, and prevention of seawater intrusion in coastal aquifers. The project also evaluates longterm risks associated with persistent CECs, addressing critical knowledge gaps that currently limit regulatory guidance and operational decisionmaking.

Through strong engagement with water utilities, municipalities, environmental agencies, and industry partners, AQUICIRC ensures that scientific advances translate into practical improvements in MAR management. Expected outcomes include optimized recharge strategies, improved risk assessment frameworks for CECs, enhanced modelling tools for water quantity and quality, and evidencebased recommendations for integrating unconventional water sources into regional water cycles. These results will support safer and more efficient water reuse, contributing to climate resilience, reduced pressure on freshwater resources, and progress toward SDG 6 (Clean Water and Sanitation) and SDG 14 (Life Below Water).

By leveraging transnational collaboration and knowledge exchange between Africa and Europe, AQUICIRC delivers added value that extends beyond individual case studies. The project strengthens capacity in regions with limited resources, informs policy debates in countries where MAR with treated wastewater is not yet permitted, and provides scalable, adaptable solutions for sustainable groundwater management worldwide. Through its multidisciplinary approach, AQUICIRC advances the state of the art in MAR and positions circular water systems as a cornerstone of future water security.



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Project partners

- UNIVERSITY OF PADOVA - ITALY
- POLYTECHNIC UNIVERSITY OF CATALONIA - SPAIN
- NATIONAL AGRONOMIC INSTITUTE OF TUNISIA - TUNISIA
- STELLENBOSCH UNIVERSITY - SOUTH AFRICA
- UNIVERSITY OF THE WESTERN CAPE - SOUTH AFRICA
- IO-THINGS - BELGIUM

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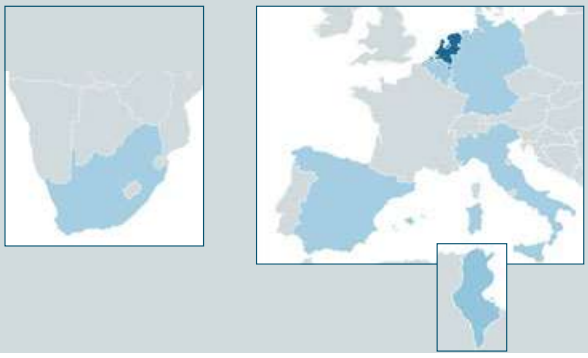

KEYWORDS

managed aquifer recharge (MAR), circular water economy, contaminants of emerging concern (CECs), PFAS, permeable reactive materials (PRM), groundwater quality, infiltration basins, direct injection, nature-based solutions (NBS), IoT groundwater monitoring, wastewater reuse, hydrogeological modelling, seawater intrusion prevention