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Ancient Hydro-Technologies as a Response to Climate and Food Emergencies: The Use of Cultural Heritage to Rescue the Future

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Abstract

The Mediterranean faces escalating climate challenges, including rising temperatures, water scarcity and ecosystem degradation. Projections indicate up to 6.5°C warming by 2100, with reduced rainfall and increased evaporation intensifying water shortages — especially in agriculture, which uses 70–80 per cent of the region's water. Freshwater competition, declining crop yields and coastal aquifer salinization further threaten sustainability. Ancient hydro-technologies — developed by early civilizations — offer valuable lessons for adaptation. Minoan rainwater systems, Roman aqueducts and Iranian qanats emphasized water conservation, efficient irrigation and flood control. Designed in harmony with nature, they embody sustainability, resilience and multifunctionality, supporting biodiversity and adaptation. Scaling up these systems requires integrated governance, legal recognition, capacity building and interdisciplinary research. International cooperation and funding can help preserve and adapt them to modern needs, integrating them into the water-energy-food-ecosystem (WEFE) nexus for sustainable resource management.

KEYWORDS

SETs
WEFE nexus
Climate emergency
Nature-based solutions
Ancient hydro-technologies

WATER ICONS

Policy Recommendations

- Integrate ancestral hydro-technologies into national and regional water policies by promoting them as nature-based solutions for climate adaptation and water security. This can be achieved through regulatory frameworks, incentives for implementation, and alignment with existing environmental and agricultural policies.
- Support capacity building and knowledge exchange.
- Establish financial mechanisms and incentives.
- Strengthen multi-level governance and stakeholder engagement.
- Enhance monitoring and data integration by incorporating ancestral hydro-technologies into water management planning.

< Fig. 1 Zenu ancestral hydro-technology, Colombia (Source: Jordi Morató Farreras, 2020).

Introduction

The accelerating pace of climate change (CC) has exacerbated long-standing socio-environmental issues in the Mediterranean region. These challenges arise from a combination of factors, including shifts in land use, poor management of natural water resources, soil degradation due to erosion, increasing pollution levels and a decline in biodiversity. Today, over 180 million individuals in the Mediterranean region are affected by water scarcity.

Projections based on the latest findings from the IPCC (2023) and MedECC (2020) reports indicate a worsening scenario. Annual mean temperatures on land and sea across the Mediterranean basin are 1.5°C higher than during pre industrial times and they are projected to rise by 2100 by an additional 3.8 to 6.5°C for a high greenhouse gas concentration scenario (RCP8.5) and 0.5 to 2.0°C for a scenario compatible with the long-term goal of the UNFCCC Paris Agreement to keep the global temperature well below +2°C above the pre industrial level (RCP2.6). Without additional mitigation, regional temperature increase will be 2.2ºC in 2040, and for each degree of global warming, mean rainfall will likely decrease by about 4 per cent and evaporation will increase nearly 7 per cent in much of the region, particularly in the south. On land and in the sea, heat waves will intensify in duration, with higher peak temperatures. Despite strong regional variations, summer rainfall will likely be reduced by 10 to 30 per cent in some regions, increasing existing water shortages, desertification and decreasing agricultural productivity, which could be reduced by 17 per cent in 2050 (MedECC 2020).

With agriculture using most of the Mediterranean's water (about 70 to 80 per cent) (Crovella et al. 2021), which is in competition with fresh water, touristic and industry sectors in a very volatile equilibrium, and climate change impacting water reserves, several challenges arise, including less runoff and groundwater, poorer water quality, more conflicts among stakeholders, ecosystem damage, coastal aquifer salinization and fewer nutrients for sea organisms, which affects fishing, one of the most important sources of protein in parts of the region.

Demand for irrigation is expected to increase by 4 to 18 per cent by 2100, although demographic change, including the growth of large urban centers, could enhance this demand by 22 to 74 per cent. Most significant climate risks are related to a shortage and excess of water, as shown in recent analyses of the Nationally Determined Contribution (NDCs) for the Paris Agreement, at the global level and for Africa specifically (Tollin et al. 2022). However, the NDCs are only defining actions to certain degree, and in only a few cases through an integrated, cross-sectoral and multi-risk approach.

Despite challenges, the Mediterranean region has significant potential for adaptation by improving water use efficiency. Human societies have historically demonstrated resilience by developing socio-technical, cultural and environmental systems (SETs) that integrate traditional knowledge, cultural practices and technologies. These adaptive systems, recognized by scientists as SETs (Grimm et al., 2017; Reyers et al., 2018; Preiser et al., 2018; Nguyen et al., 2023), have enabled communities to endure and respond to environmental challenges while maintaining ecological balance. They reflect centuries of sustainable resource management and a deep connection between people and nature.

Ancient Hydro-Technologies: Lessons from Water Heritage

Ancient hydro-technologies are a key component of adaptive strategies developed by ancient civilizations to manage water sustainably. Designed in harmony with natural hydrological cycles, these systems ensured water conservation, efficient irrigation and the regulation of floods and droughts, serving as nature-based solutions to climate variability.

These traditional water management systems and engineering practices were developed to harness, store, distribute and regulate water resources while maintaining ecological balance. By integrating traditional knowledge with ecosystem management, they supported long-term water availability for agriculture, domestic use and biodiversity preservation. Rooted in nature and adapted to local environmental conditions, ancient hydro-technologies exemplify NbS, demonstrating how human societies have historically leveraged natural processes for resilience and sustainable development.

Water management has played a crucial role in the development of civilizations across the Mediterranean, shaping their resilience, sustainability and prosperity. Over time, societies adapted and improved water infrastructure to address the challenges of arid climates, urban expansion and agricultural needs. Each period contributed to the evolving water heritage of the Mediterranean, demonstrating how civilizations adapted to environmental challenges through technological ingenuity and sustainable water management practices.

Egyptian water culture (c. 3150–31 BCE), was deeply connected to the Nile River, which served as the foundation for the development of sophisticated irrigation systems. The Egyptians implemented basin irrigation, canals and reservoirs to control seasonal flooding and sustain agriculture. They also constructed nilometers to measure water levels and predict harvests, demonstrating early hydrological expertise (Gad 2008; Driaux et al. 2016). In the Minoan civilization (c. 3000–1100 BCE), water management systems became highly advanced, with the construction of complex drainage and supply networks. The Minoans engineered underground clay pipes, terracotta aqueducts and multi-tiered cisterns to ensure a steady water supply. They also developed sophisticated rainwater harvesting techniques and built some of the earliest known flushing toilets, particularly in palatial centers like Knossos (Angelakis et al. 2013; Crovella et al. 2021). The Etruscans (c. 800–500 BCE) in central Italy contributed significantly to water infrastructure by constructing tunnel aqueducts, drainage canals and artificial reservoirs to manage water for both agricultural and urban use. The Romans (c. 100 BCE–476 CE) perfected aqueduct technology, enabling them to transport water over long distances with precision-engineered arches and tunnels. They constructed extensive public infrastructure, including baths, latrines, fountains and sewage systems, setting a foundation for modern urban water management. In the medieval period (fifth–fifteenth century CE), water management practices evolved differently across regions. While some areas experienced a decline in infrastructure following the fall of Rome, others flourished under Islamic and Byzantine influences. Islamic engineers in Spain and North Africa refined irrigation networks, introduced qanats and waterwheels (*norias*), and enhanced agricultural productivity through sophisticated water distribution techniques.

Without a doubt, the Minoans can be regarded as pioneering architects of many advanced water management techniques that continue

^ Fig. 2 Water heritage cultures of the Mediterranean and convergent evolution in other world areas (Source: Jordi Morató Farreras, 2023; Background map: Nzeemin, 2012. CC BY 3.0, via Wikimedia Commons).

to influence modern systems today. Important aspects of this water heritage include the following:

- They recognized the vital role of sanitation, water supply, and drainage systems in human survival and well-being, integrating these elements into urban planning to ensure the sustainable management of water resources.
- Water quality and safety were key considerations in the design and construction of their water supply systems, reflecting an advanced understanding of hydrology and public health.
- They employed a balanced approach, combining small-scale solutions like cisterns for rainwater collection with large-scale infrastructure such as reservoirs to store and regulate aqueduct flows.
- Their water technologies were characterized by their simplicity, efficiency and ease of operation, requiring minimal maintenance and complex controls while effectively meeting the needs of growing urban populations.

Parallel developments occurred among various civilizations, each geographically isolated from the Mediterranean, yet independently devising comparable water management strategies to sustain their communities. This phenomenon of convergent evolution, where different societies develop similar solutions in response to shared environmental challenges, was particularly significant in the Indus Valley (Pakistan) during the Bronze Age (c. 3200–1100 BCE), the Zenú society in Colombia (c. 600–400 BCE), and the Pre-Hispanic Amunas in Peru (twelfth–thirteenth century). These civilizations engineered sophisticated water systems tailored to their landscapes, demonstrating a deep understanding of sustainable resource management.

Key Properties of Ancient Hydro-Technologies

These water management systems and agricultural conservation practices, guided by traditional ecological knowledge and community-based governance, have shown centuries-long sustainability and resilience, enduring extreme events while efficiently utilizing resources. Good examples of such systems, including some still in use today, can be found all over the world: the acequias de careo in Spain, the zenu channels or camellones in Colombia, the Aflaj and Zajirah in Oman, the traditional stone weirs in ephemeral streams in Greece, the Persian qanat in Iran and the drystone walls in many parts of the Mediterranean region such as in Catalonia (Spain) and Cinque Terre (Italy) to name a few, but also the terraces built on sloping terrain in many Mediterranean areas to help level the land, making it more suitable for agriculture, while also reducing soil erosion caused by rainfall.

If properly managed, these technologies could become an effective solution for CC adaptation and mitigation related to flood and drought control and disaster risk reduction, water regulation, ecosystem services and biodiversity conservation, among other challenges. They also provide multifunctional co-benefits for the management of pollution, food production, health security and economic development. From a cultural perspective, these technologies represent a wealth of ancient local and traditional knowledge that should be preserved and valued as cultural heritage. In summary, key properties of ancient hydro-technologies, which provide valuable insights for modern water management and climate adaptation strategies, include:

1. Sustainability and ecological integration. Ancient hydro-technologies have a low footprint in terms of energy, resources and carbon. Designed in harmony with natural water cycles, these systems minimized environmental disruption and ensured long-term resource availability.
2. Adaptability to local conditions. Tailored to specific geographic and climatic contexts, ancient hydro-technologies optimized water use in arid, mountainous, and flood-prone regions.
3. Efficiency in water conservation. Many techniques, such as terraced irrigation, qanats and amunas, prioritized water infiltration, storage, and controlled release to reduce losses and maximize usage.
4. Decentralized and community-based management. These systems operated through local knowledge and collective governance, ensuring equitable distribution and maintenance.
5. Resilience to climate variability. Designed to mitigate droughts, floods and seasonal changes, these technologies provided stable water access in extreme conditions.
6. Beneficial for biodiversity restoration, ancient hydro-technologies can be instrumental in preserving and restoring biodiversity and strengthening ecosystem services' provision.
7. Low-tech, high-impact design. Simple yet effective engineering principles made these systems durable, cost-efficient and easy to maintain over centuries.
8. Integration with the WEFE nexus. Ancient hydro-technologies serve the further integration of the WEFE nexus at the local and regional scale as a result of their transfunctionality and their contribution to the Sustainable Development Goals (SDGs).
9. Multifunctionality. They often served multiple purposes, such as irrigation, drinking water supply, flood control and soil conservation, contributing to overall ecosystem stability.

Ancient Hydro-Technologies as a Solution to Climate and Food Crises

Ancient hydro-technologies should be recognized not only as historical infrastructure and cultural heritage but also as viable models for sustainable water management, adaptable to present and future challenges. Their effectiveness can be further enhanced by integrating innovations from social, ecological and engineering disciplines.

Many of these systems have significant potential for recovery and scaling, offering solutions for the transformative changes needed to address global challenges within the broader framework of sustainable development. Their value in tackling current crises – climate change, biodiversity loss, water scarcity, health and food security – has been well-documented with extensive evidence, case studies and the identification of best practices.

The implementation of ancient hydro-technologies today faces legal, economic, technological and governance challenges. Regulatory frameworks often fail to support traditional practices, while knowledge gaps, financial constraints and the erosion of traditional expertise hinder their revival. Additionally, urbanization, land use changes and competing water demands limit their applicability. Addressing these barriers requires policy reforms, institutional support, capacity building and interdisciplinary collaboration. Multi-level governance, financial investment and integrated planning are essential to effectively reintegrate these sustainable water management systems into modern contexts.

In summary, successfully scaling up ancient hydrohydro-technologies requires addressing the following critical challenges:

- Multi-level governance to align national policies with local practices and integrate sectoral policies on climate, water, energy, food, biodiversity, health and development.
- Legal recognition and protection of ancient hydro-technologies at risk of loss.
- Capacity building for policymakers, practitioners, researchers and communities to advance theoretical and operational knowledge.
- Multidisciplinary research integrating low- and high-tech solutions, scientific, socio-cultural and traditional knowledge, and the role of eco-museums.
- Awareness and advocacy to highlight the value of ancient hydro-technologies in resilience transitions.
- Financial support for large-scale demonstrations of these technologies that can inspire transformative change.
- Global networks for knowledge exchange, project development and implementation.

Despite these challenges, ancient hydro-technologies are gaining renewed interest. Cities and rural communities are integrating traditional systems like qanats, acequias and stepwells with modern innovations such as remote sensing and decentralized water governance. These hybrid approaches offer scalable, nature-based solutions for enhancing water resilience and sustainable management in a changing climate.

Conclusion

Ancient hydro-technologies represent nature-based solutions rooted in traditional knowledge and ecosystem practices, offering sustainable approaches to water management. These systems are characterized by low energy requirements, resource efficiency and minimal carbon footprints. By integrating ecological principles, they not only restore biodiversity but also enhance ecosystem services, such as hydrological regulation, artificial aquifer recharge and soil moisture retention. These benefits, in turn, improve carbon sequestration, soil fertility and local temperature regulation, making them invaluable for climate adaptation and resilience.

These time-tested systems provide critical insights for addressing contemporary environmental challenges. Their ability to optimize water conservation, enhance irrigation efficiency and mitigate the impacts of floods and droughts has been proven over centuries. By reintegrating ancient hydro-technologies into modern water governance, new research opportunities emerge, highlighting their potential to strengthen sustainability and resilience in the face of climate change. However, realizing their full potential requires embedding them in modern policies through multi-level governance, robust legal frameworks, capacity building and interdisciplinary research.

As global water scarcity intensifies, combining these traditional practices with modern innovations can foster adaptive, nature-based water management strategies. Their multifunctionality supports biodiversity conservation, food security, and ecosystem services, aligning with the WEFE nexus and the SDGs. Scaling up these technologies demands financial investment, cross-sector collaboration and awareness-raising initiatives to ensure their preservation and adaptation to future challenges.

By bridging traditional wisdom with modern innovation, ancient hydro-technologies can play a pivotal role in advancing climate resilience and sustainable water management, not only in the Mediterranean but globally. Recognizing their value and integrating them into broader strategies will be essential for building equitable and resilient water systems for the future.

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