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UNESCO Water Structures: Heritage, Innovation and Sustainable Use

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Abstract: Ancient water structures, such as Roman aqueducts and Persian qanats, reflect past civilizations' sophisticated engineering and resource management skills. Roman aqueducts supported urban, agricultural, and sanitary systems through precise design and extensive networks, while Persian qanats provided consistent access to groundwater in arid climates. Both structures, recognized by UNESCO as World Heritage sites, embody significant cultural, historical, and technical values. This study focuses on a selection of these ancient systems, chosen for their exemplary representation of diverse approaches to water management, to explore their sustainable principles, adaptive reuse, and integration into modern environments. The study highlights their continued relevance in landscape architecture and water management practices while acknowledging the limitations of the study's scope to specific ancient examples.

Keywords: Ancient Water Structures; Sustainable Resource Management; Adaptive Reuse; Heritage Conservation; UNESCO World Heritage.

Introduction

Ancient waterworks, such as Roman aqueducts and Persian qanats, represent the pinnacle of engineering skill and technology in antiquity. Beyond their functional role, these structures also served as aesthetic and landscape features, influencing the evolution of water management and landscape design technologies in subsequent eras. Many of these systems are inscribed on the UNESCO World Heritage List, highlighting their dual significance as technical and cultural landmarks. Qanats, for example, remain active in around 34 countries (Moosavi, 2006), with a notable concentration in Iran, where eleven qanats were recognized as UNESCO World Heritage sites in 2016 (ICOMOS, 2016). Similarly, many Roman aqueducts hold a dominant visual presence in their respective landscapes. While differing in design and historical context, they are united by their enduring role as important tourist destinations and symbols of cultural identity, contributing to the heritage and economy of their modern communities.

The Segovia Aqueduct, located in Segovia, Spain, built around 50 AD, is one of the best-preserved Roman aqueducts. This imposing structure, with its double-tiered arches, has been a UNESCO World Heritage site since 1985 (UNESCO, 1985, p. 10). It remains significant for the residents of Segovia today, serving as both a city symbol and a tourist attraction. Similarly, the Bozdoğan Kemeri, part of the Valens Aqueduct in Istanbul, Turkey (Figure 1), has become a prominent landmark in the Fatih district and a city symbol. It was included among the Historic Areas of Istanbul as a UNESCO World Heritage site in 1985 (UNESCO, 1985, p. 11). The Pont du Gard in southern France celebrates Roman engineering prowess with its impressive structure and long history. It was inscribed as a UNESCO World Heritage site in 1985 (UNESCO, 1985, p. 8). A somewhat different example is the aqueduct and canal system at Las Médulas in León, Spain**,** which is crucial for efficient gold mining and processing. It was inscribed on the UNESCO World Heritage List in 1997 (ICOMOS, 1997). Its inclusion, however, was controversial, as some regard the site as a product of destructive human activity that poses challenges to environmental protection and promotion.

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Figure 1. Aqueduct of Valens, 4th century AD, Istanbul.
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Though many ancient waterworks have not survived, those remain as enduring symbols of the ingenuity and adaptability of past civilizations. Their preservation and visibility in modern landscapes often stem from their historical significance and cultural importance, even if their original functions are no longer used (Figure 2). These structures, ranging from operational systems to partial ruins, illustrate the challenges of time and the efforts required for their conservation. Their inclusion on the UNESCO World Heritage List highlights their Outstanding Universal Value (OUV), a standard established by the 1972 World Heritage Convention (UNESCO, 1972).

This status acknowledges human creative genius, cultural traditions, aesthetic significance, ecological relevance, and the necessity of authenticity and integrity to maintain their historical significance. Despite global recognition, these systems' survival and continued relevance often rely more on local stewardship and adaptive reuse. This involves preserving their structural integrity and reimagining their use to meet contemporary needs. Adaptive reuse may include educational programs, sustainable tourism, or community projects, while local stewardship ensures ongoing care, knowledge transfer, and integration into regional development strategies.

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Figure 2. Aqueduct in Kharanaq near Yazd, Iran
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This study investigates ancient water systems' adaptive reuse and sustainability, focusing on their integration into contemporary settings. A desk-based methodology uses UNESCO World Heritage documentation, site reports, and scholarly literature to evaluate examples selected for their historical, technical, and geographical significance. Roman aqueducts and Persian qanats, exemplary water delivery systems designed to transport water over long distances, form the core of this analysis. Their durability reflects the use of large-scale infrastructure and resilient materials. However, prolonged exposure to natural elements has rendered them more vulnerable to environmental pressures than smaller, localized water systems. Despite variations in functionality, these ancient systems provide valuable insights into sustainable water management and cultural heritage preservation. By analyzing both operational and non-operational examples, the study identifies principles of resilience and adaptability that remain relevant to addressing modern environmental challenges. While not evaluating UNESCO's policies comprehensively, this study calls for further research into the socio-economic impacts of these systems, particularly their integration into modern landscapes. Such investigations can provide valuable insights into preserving these ancient marvels while inspiring future water and heritage management approaches.

Functionality and long-term use

Ancient water structures have adapted to changing needs and challenges for centuries, with some still performing their original functions. The following examples demonstrate how they continue to support local communities while preserving their historical and cultural significance. The Aqua Virgo in Rome, Italy, is essential to the city's historic infrastructure (ICOMOS, 1980). It still supplies water to landmarks such as the Trevi Fountain. The functioning qanat in Gonabad, Iran, known as Qanat-e Zarch (Kariz e Kay Khosrow), is remarkable for its length of nearly 100 kilometers and depth reaching up to 300 meters in certain sections. For over 2,700 years, it has provided drinking and irrigation water to local communities. Likewise, ancient qanats, originating around the turn of the Common Era, continue to supply drinking water to Yazd, Iran, and its

surroundings (Figure 3). These systems and other cultural landmarks were inscribed as UNESCO World Heritage sites in 2017 (ICOMOS, 2017). The Aflaj Irrigation Systems of Oman, another UNESCO World Heritage site, represent five individual irrigation systems among the approximately 3,000 still-functioning aflaj in Oman, dating back to around 500 AD. Although known locally as aflaj, these systems function similarly to qanats, using gravity-fed, underground channels to transport water across arid landscapes. They have sustained Omani communities for centuries, with evidence of similar structures as early as 2500 BC (ICOMOS, 2006).

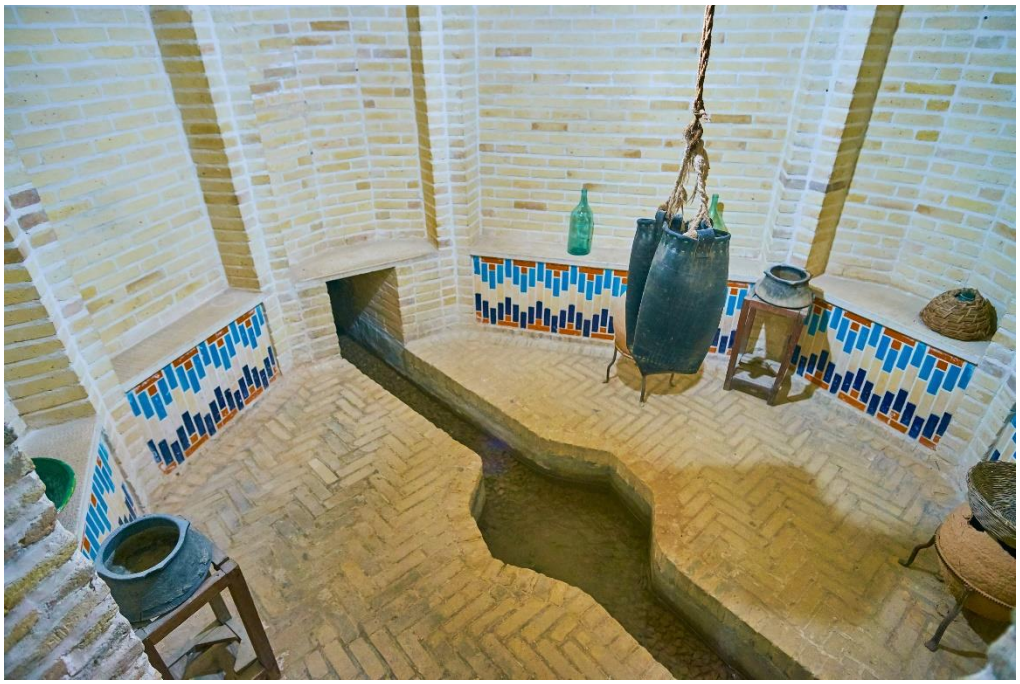

Figure 3. Qanat Hall of Tehraniha House, Yazd, Iran
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Regular maintenance and repairs are essential for the long-term preservation of historical water structures, as evidenced by their enduring functionality over centuries. The precise engineering, use of durable materials, and diligent upkeep of these systems have enabled them to withstand natural wear, technological changes, and sociopolitical shifts. For example, the Bozdoğan Kemeri in Istanbul functioned well into the modern period (Müller-Wiener, 1977, p. 274).

The Tarragona aqueduct, located in Tarragona, Spain (Figure 4), a UNESCO World Heritage site since 2000 (ICOMOS, 2000), remained operational until the 19th century (Leather, 2002, pp. 50–54). Similarly, the Segovia Aqueduct, built in the 1st century AD, served until the 20th century, as did Solomon's Pools and the primary water channels of Jerusalem, located in modern-day Israel and Palestine (Barghouth & Al-Sa`ed, 2009). Historical qanats, such as those channeling water from aquifers (Wessels, 2016), exhibit remarkable resilience. They could transport water across considerable distances through sophisticated engineering solutions, like the careful grading of underground tunnels (Ghasemi et al., 2013).

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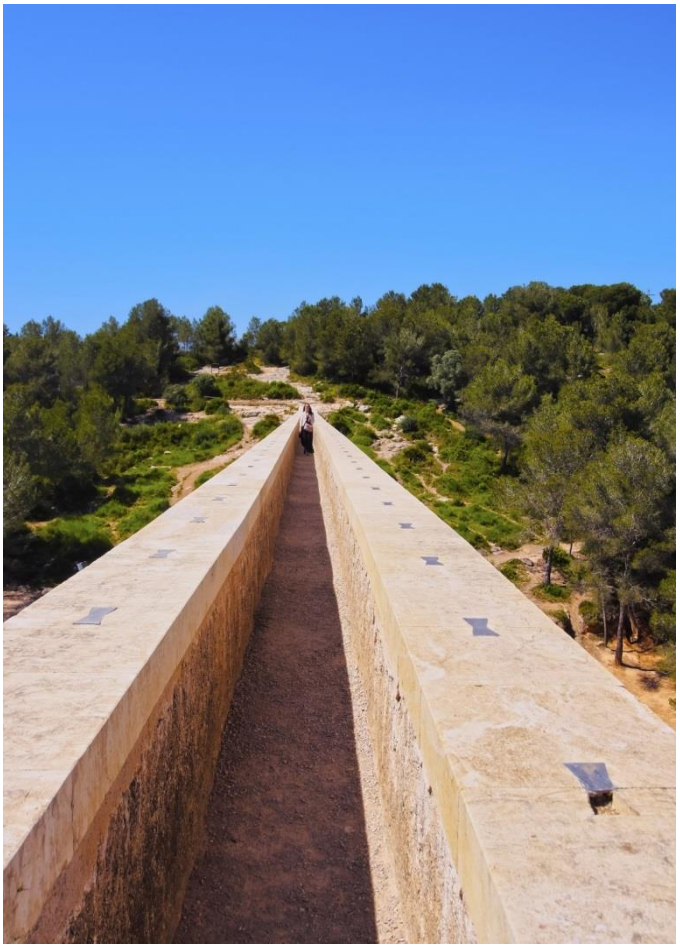

Figure 4. Les Ferreres Aqueduct in Tarragona, Spain
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The Manawir Irrigation System, located in the Kharga Oasis, Egypt, on UNESCO's tentative list since 2015 (UNESCO, 2015a), exemplifies the durability and maintenance efforts that have sustained ancient water management systems over centuries. Initially constructed by the Persians in the 8th century BC, this system utilized underground aqueducts to channel water via gravity, ensuring agricultural productivity in arid conditions. The Romans later expanded the system, demonstrating a commitment to adapting and maintaining its functionality to serve larger communities and broader economic needs. Similarly, the Great Wall of Gorgan, Iran, incorporated canals for large-scale brick production, with the surviving qanat Sadd-e Garkaz still intact for over two millennia, standing as a testament to effective maintenance and robust construction techniques (UNESCO, 2017). The Titus Vespasian Tunnel, located near Seleucia Pieria, Turkey (Figure 5), a structure comparable to qanats and listed on UNESCO's tentative list since 2014 (UNESCO, 2014), was engineered to redirect floodwaters from the Nur Mountains, protecting the nearby harbor from sediment buildup. This impressive structure exemplifies Roman innovation in water management, serving as one of the most extensive water tunnels of its time and demonstrating remarkable resilience in handling significant water flows.

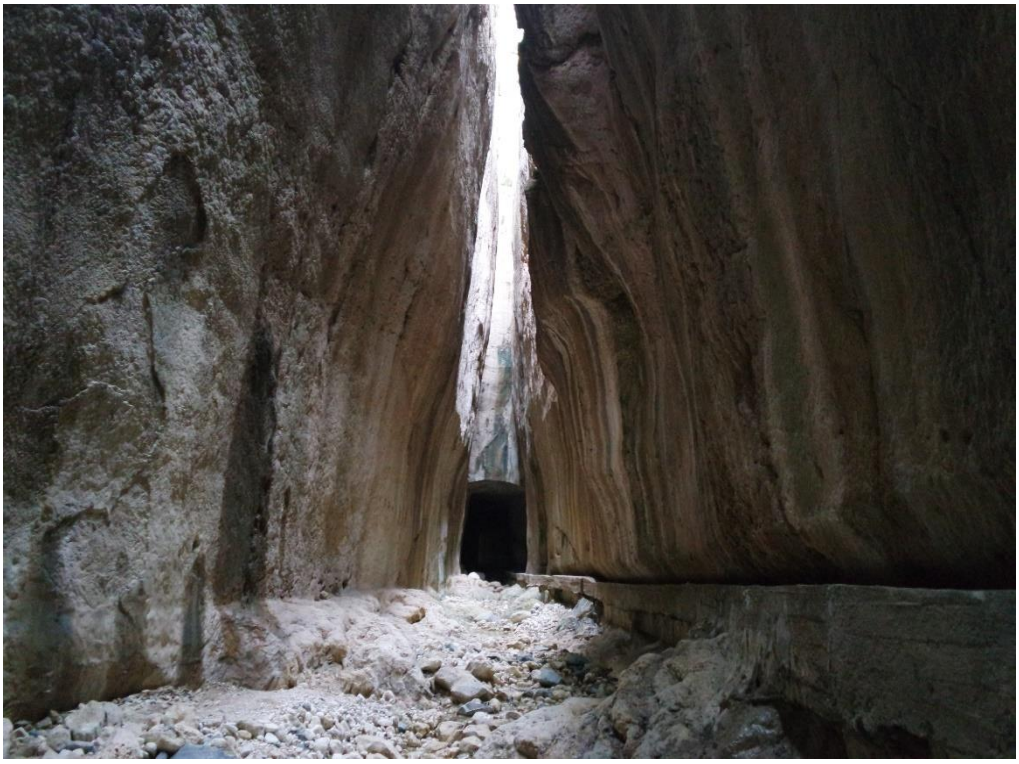

Figure 5. Titus Vespasian Tunnel, Seleucia Pieria, 1st–2nd century AD
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The transformation of these structures involves maintenance and repairs and adaptation to new technological, social, and environmental demands. For example, after the earthquake in Apamea (modern-day Syria) in 115 AD, aqueducts were repurposed as part of defensive walls. Apamea is included on UNESCO's tentative list (UNESCO, 1999). Similar adaptations of existing water systems for defensive purposes can be seen in Amathus, Cyprus (Angelakis et al., 2012, pp. 330–335) and Thessaloniki, Greece (Yannopoulos et al., 2017). The Pont du Gard, used as a pedestrian bridge over the Gardon River during the Middle Ages, was modified in the 18th century to accommodate horse-drawn carriages (Fernández Casado, 1968). Over time, the ownership and uses of water structures changed to meet new communal needs. For instance, in Córdoba, Spain**,** the Aqua Fontis Aureae aqueduct**,** following the Muslim conquest, served as a water source for the Great Mosque of Córdoba, which later became a cathedral (Sánchez et al., 2016, pp. 181–192). The historic center of Córdoba has been a UNESCO World Heritage site since 1984.

Contemporary research underscores the importance of aligning maintenance and restoration practices with broader political and social dynamics, as outlined by UNESCO (2015b) principles, which remain highly relevant today. Throughout history, the upkeep of water structures has adapted to these broader contexts. In the post-Roman world, aqueducts symbolized more than engineering achievements—they embodied political stability and cultural heritage, with their maintenance and repair often driven by prevailing political and social priorities. The Visigothic monarchy on the Iberian Peninsula saw these structures as a means of connecting to the imperial past and legitimizing their power. During the early Middle Ages, bishops were crucial in managing and maintaining ancient aqueducts. As leaders of local communities, they replaced defunct Roman authorities and, leveraging their organizational skills and resources, maintained these vital structures (Martínez Jiménez, 2012). In Barcelona and Valencia, Spain, ancient aqueducts were successfully integrated into new water supply systems that lasted until the 10th and 11th centuries. In Tarragona, the Church used the Gaià aqueduct almost exclusively for its needs, as evidenced by the construction of cisterns in the 6th century. However, the aqueduct was brought back into operation during the

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Islamic period, as al-Idrisi's chronicle in the 11th century mentions it as a water source for mills in the port suburb of Tarragona (Martínez Jiménez, 2012). In subsequent centuries, the mills were located in the port area and powered by the same aqueduct that drew water from the Roman-era source.

Framework of sustainable heritage

UNESCO's heritage protection framework has evolved to emphasize a holistic approach to sustainability, recognizing historic sites as cultural treasures and practical assets. This shift began with the 2010 *World Heritage Convention and Sustainable Development* document, which established a foundation for balancing preservation with sustainable use (UNESCO, 2010). The framework gained further depth during the Paraty meeting, where heritage conservation was redefined to highlight historical sites' economic and social significance, particularly their roles in tourism and community development. This momentum was reinforced in the 2012 Ouro Preto meeting, which linked heritage preservation to broader sustainability objectives, as outlined in the *Proceedings of the Consultative Expert Meeting on World Heritage and Sustainable Development* (UNESCO, 2012). A key outcome was an Action Plan that prioritized local participation in heritage management, reflecting UNESCO's commitment to interdisciplinary and community-focused conservation. Integrating traditional practices and empowering local communities is essential for ensuring conservation strategies respect regional values while aligning with global preservation goals (Sullivan, 2004, p. 50).

In 2015, UNESCO formalized this commitment through its *Policy Document on World Heritage and Sustainable Development*, which integrates environmental, social, and economic considerations into preservation strategies. Recognizing the impacts of climate change and social inequities on heritage, the policy underscores the importance of local communities as active partners in conservation efforts (UNESCO, 2015b). By weaving together climate resilience, social inclusion, and emergency response, UNESCO has created a comprehensive approach to heritage conservation (UNESCO, 2023a). Climate-focused initiatives aim to protect sites from extreme weather events, while community engagement programs—particularly those targeting marginalized groups—ensure equitable and inclusive management practices. The success of these frameworks depends on fostering strong connections between heritage sites and their surrounding communities, ensuring that conservation strategies reflect the needs of locals and tourists (Zbuchea, 2020, p. 80).

The importance of stakeholder collaboration in heritage management is highlighted by Chennaoui (2024) in his study on the preservation and tourism potential of the Roman aqueducts in Algeria. He underscores the need to involve local communities, professionals, and policymakers to address governance challenges and promote sustainable tourism. Drawing on the Historic Urban Landscape (HUL) approach and examples from France, the study demonstrates how collaborative strategies can enhance preservation and tourism. Expanding on this, a "living heritage" approach positions heritage sites as dynamic spaces that integrate cultural, economic, and social dimensions, encouraging community participation and fostering deeper connections with these sites (Poulios, 2014, p. 22). Such findings align with UNESCO's focus on community-driven stewardship, emphasizing inclusive frameworks for maximizing the cultural and economic value of heritage sites.

Recent research further supports the need for community-centered approaches. Mousazadeh et al. (2023) highlight how sustainable tourism behaviors are critical to preserving Persian qanats. Their study identifies the role of education and community involvement in fostering positive behavioral changes among tourists and local stakeholders. By promoting awareness of the qanats' cultural and ecological importance, such initiatives enhance long-term preservation while supporting sustainable tourism

practices. These findings align with the ICQHS's mission and illustrate how UNESCO's framework is actively implemented on the ground. This localized approach is exemplified by the work of the International Centre on Qanats and Historic Hydraulic Structures (ICQHS) in Yazd, Iran. Established under UNESCO's auspices, ICQHS is dedicated to studying, preserving, and promoting qanat technology and other historic hydraulic systems. The center emphasizes knowledge transfer and capacity-building initiatives to integrate traditional water management practices into contemporary sustainable development frameworks. In 2023, UNESCO's Executive Board recognized the ICQHS for its exemplary performance as a category two center, renewing its designation under UNESCO's auspices (UNESCO, 2023b).

Challenges in preservation

The preservation of historical water structures relies on a framework designed to address threats to their Outstanding Universal Value (OUV). In 2008, after consulting experts in natural and cultural heritage, the World Heritage Committee developed a standardized list of factors such as climate change, natural disasters, and urbanization, facilitating consistent risk assessments across regions and heritage types (UNESCO, 2008). This framework enhances understanding of how global threats affect cultural assets and underscores the need for coordinated conservation strategies. Although these structures are inherently durable, they remain susceptible to environmental pressures and insufficient maintenance. To mitigate these risks, UNESCO has introduced crisis management strategies highlighting heritage sites as symbols of identity and stability, especially during conflicts and natural disasters, emphasizing their vital role within communities. More detailed, site-specific guidance is needed to fully incorporate resilience to environmental and social crises into preservation practices. Tailored approaches addressing each site's unique economic and ecological context would strengthen the framework and ensure that preservation aligns with local values and regional priorities.

Contemporary challenges, such as pollution, urbanization, and limited restoration funding, alongside climate-related threats like droughts and floods, further highlight the fragility of these structures. Historically, natural disasters have also left a lasting impact on aqueducts and qanats. For example, in 1881, heavy rains destroyed an ancient dam near Consabura (modern-day Consuegra), Spain, resulting in severe floods and significant loss of life in the nearby town of Consuegra (Díaz Marta, 1984). The Aspendos aqueduct, located in modern-day Turkey (Figure 6), included on the UNESCO World Heritage Tentative List (UNESCO, 2015c), has already suffered extensive damage in antiquity, with its active use likely lasting no more than 150 years (Kessener, 2000). Similarly, Aqua Augusta, a Roman aqueduct in southern Italy, sustained damage from seismic events and eruptions of Vesuvius, while bradyseism in the Campi Flegrei region led to the deformation and flooding of several sections.

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Figure 6. Aqueduct in Aspendos, 2nd century AD
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Over time, recognizing these structures' importance has driven efforts to preserve their historical and cultural value, including their inscription on the UNESCO World Heritage List (ICOMOS, 2004), which has spurred restoration initiatives. A notable example is the Arg-e Bam Citadel in Kerman Province, Iran, along with its surrounding cultural landscape, including qanats, which suffered severe damage in the 2003 earthquake. Subsequent restoration initiatives have preserved much of its structural integrity and historical authenticity. However, climate change remains a critical threat to these sites, with rising temperatures, more frequent extreme weather events, and declining groundwater levels further endangering their stability (UNESCO, 2008). Qanats are particularly vulnerable to modern agricultural and industrial practices, including groundwater contamination and over-extraction. In Iran, where qanats have historically sustained civilizations in arid regions, over 40,000 systems once existed. However, increasing pressures such as urban expansion and agricultural intensification have left most in disrepair. In the Mashhad plain, a region once dense with qanats, only a tiny fraction of shafts recorded in 1961 remained functional six decades later (Maghrebi et al., 2022).

Similar patterns are evident in other arid regions, including North Africa, Latin America, and China, where mechanized pumps, large-scale irrigation, and urban development have contributed to the abandonment of qanats. Additionally, the decline of traditional knowledge and a shortage of skilled artisans required for qanat maintenance has further exacerbated the problem (Maghrebi et al., 2022). Without regular upkeep, many historic systems face collapse or blockage, while environmental changes such as shifting rainfall patterns and groundwater depletion further threaten their viability (Goblot, 1979, pp. 37–42). Environmental pollution, encompassing water, air, and soil contamination, represents another pressing issue. This pollution poses significant risks to these structures, especially in urban areas where development pressures ancient infrastructure. For example, Roman aqueducts, like those integrated into modern cities, face challenges from air pollution and urban expansion, compromising their structural integrity.

Restoration and maintenance of historical water systems require substantial financial investment (Rinne, 2007). However, limited resources often lead to deferred repairs,

accelerating the deterioration of these structures. In the past, neglect frequently stemmed from sociopolitical upheavals, such as the relocation of the Roman capital to Constantinople, the decline of Rome's population, and barbarian invasions. After the fall of the Western Roman Empire, the absence of centralized authority and scarce resources further hindered maintenance, leaving many aqueducts in disrepair. A similar fate befell Roman aqueducts in the Iberian Peninsula, where only a few, such as the San Lázaro aqueduct in Mérida, Spain, now part of the UNESCO World Heritage List, remained in use into the 8th century (Martínez Jiménez, 2012). The approach to ancient infrastructure shifted during the Umayyad invasion and the establishment of the Islamic State in Córdoba. A period of urban renewal followed, but the emphasis on Roman heritage diminished. Some aqueducts in the Iberian Peninsula were restored in the 9th and 10th centuries. Nevertheless, once public water sources were established, many of these structures became privately controlled, supplying palaces or powering mills.

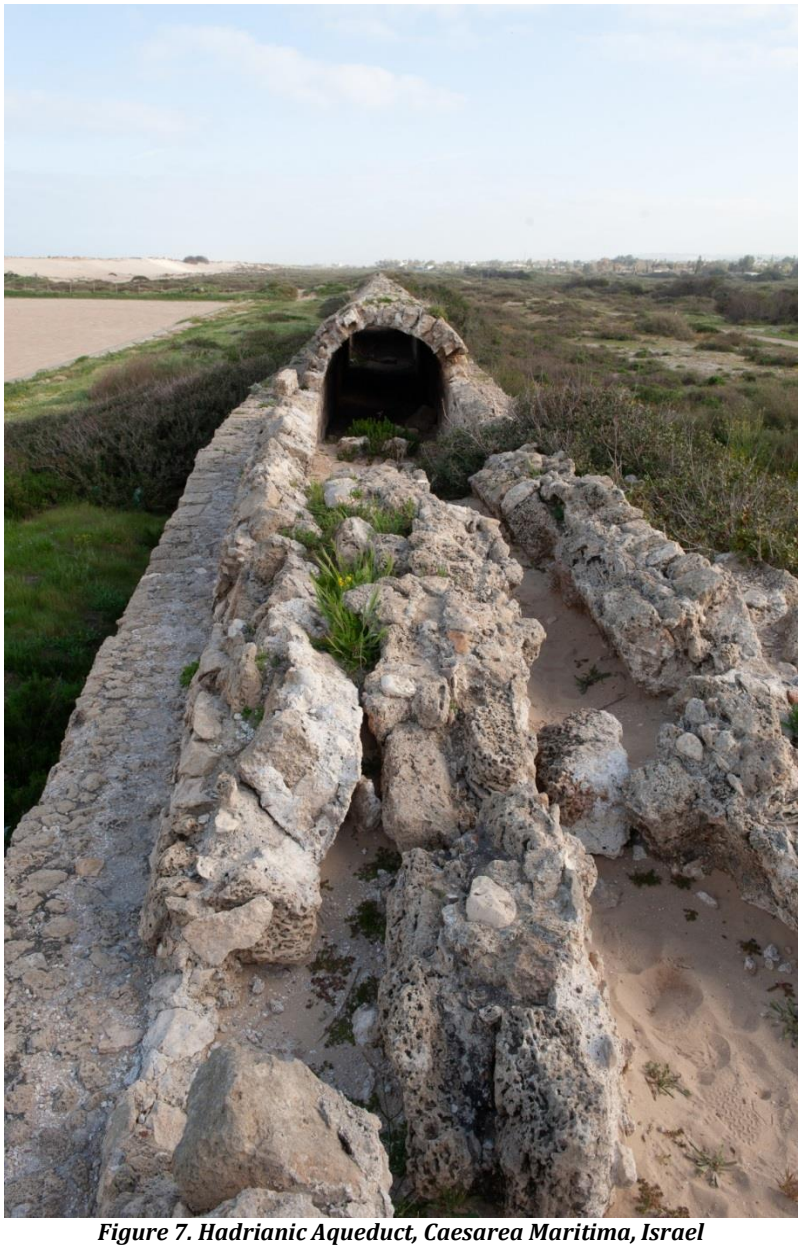

Figure 7. Hadrianic Aqueduct, Caesarea Maritima, Israel
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A similar pattern is observed in Caesarea Maritima, located in modern-day Israel, whose aqueducts (Figure 7), included in the UNESCO World Heritage Tentative List (UNESCO,

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2000), once transported water from springs about 10 kilometers northeast of the city. Their decline resulted from a combination of military conflicts, changes in political control, and insufficient resources for upkeep. During Arab rule, shifting administrative priorities often led to neglect of Roman infrastructure, while later military conflicts, including the Crusades, caused further damage. Restoration attempts in the 18th and 19th centuries were insufficient to prevent further decline (Porath, 2002). However, studies suggest that in some areas, Muslim rulers maintained and adapted Roman engineering techniques (Martínez Jiménez, 2012). Roman structures were often dismantled for building materials in the medieval and early modern periods. This practice affected the Pont du Gard, where stone from its arches was reused during the construction of a road bridge in the 18th century (Fernández Casado, 1968).

Materials from the Castellum Aquae, part of the Aqua Virgo system in Rome, were used to build medieval houses. The Aqueduct of Los Milagros, located in Mérida, Spain, now part of the UNESCO World Heritage List as part of Mérida's archaeological ensemble (ICOMOS, 1993), once supplied water to the Roman city, with parts later repurposed in local construction. During the urban revival of the 6th century, attempts to repair the Aqueduct of Los Milagros are evident in late antique masonry on one of its piers.

However, these efforts likely had limited success, as most public fountains and pipes had been dismantled by the 7th century (Martínez Jiménez, 2012). In Paris, France, and Valencia de Alcántara, Spain (Ordax & Pizarro Gómez, 2006, pp. 51-54), the remaining sections of ancient structures were used to build new aqueducts or integrated into modern water systems.

UNESCO's heritage protection framework reflects a strategic shift towards integrating preservation with broader socio-economic and environmental priorities. By emphasizing localized approaches, the framework acknowledges that successful heritage management requires tailoring strategies to regional contexts and engaging communities as active stewards. While promoting public-private partnerships and reinvesting tourism revenues offer pathways to sustainable financing, their effectiveness often depends on addressing persistent site-specific challenges. For example, in Saudi Arabia, limited resource allocation, rapid urbanization, and the tension between heritage tourism and conservation goals highlight the need for more adaptive, context-sensitive solutions (Al-Tokhais & Thapa, 2020). These challenges underscore gaps in implementation, revealing inconsistencies between global policy frameworks and local realities. Addressing these gaps requires a multifaceted approach integrating broader socio-economic and legal considerations into preservation strategies. Effective tourism management is essential to balance visitor pressure with site integrity, employing measures such as controlled access, public education, and reinvestment of revenues into conservation efforts (Richards, 2018).

Adaptive and transformative strategies that acknowledge environmental and social vulnerabilities can enhance resilience to climate change and socio-political crises (Seekamp & Jo, 2020). The enduring functionality of Iran's qanats and Oman's aflaj irrigation systems demonstrates the resilience of community-driven stewardship. These systems, supported by traditional management practices such as timed water allocation monitored by sundials, exemplify the effectiveness of communal governance in maintaining critical infrastructure. However, their continued operation also highlights vulnerabilities, including reliance on consistent community participation and exposure to environmental and economic pressures. The historical use of watchtowers to protect these systems underscores the broader significance of integrating heritage preservation with security and resource sustainability. This dual focus on protection and maintenance reveals the potential of traditional practices to inform contemporary strategies for managing heritage sites under dynamic socio-political and environmental conditions.

Restoration and reconstruction

The restoration of aqueducts and qanats aims to preserve their historical integrity while adapting them for modern use, involving collaboration among archaeologists, engineers, and urban planning specialists and emphasizing community engagement. By respecting original materials and design, this approach maintains the authentic character of these structures. The *Venice Charter* (1964), a foundational heritage conservation document by ICOMOS, introduced principles of authenticity and minimal intervention (ICOMOS, 1964). Building on this, the *Charter of Krakow* (2000) promotes adapting historic structures to contemporary needs without compromising their cultural significance, allowing them to remain functional in modern contexts (Román, 2002).

A key challenge in restoration is balancing authenticity with the need for stability, often requiring careful decisions about modern materials and technologies essential for protecting these structures. Traditional materials like lime mortar are frequently favored for their compatibility and reversibility, while contemporary materials such as epoxy resins offer durability but may disrupt historical aesthetics or integrity. During the reconstruction of the Solomon's Pools in Jerusalem**,** which are listed on UNESCO's tentative list, the ancient water infrastructure was modernized under British administration in 1924 with the installation of new pipelines that remained in use until 1967 (Barghout & Al-Sa`ed, 2009).

Similarly, the restoration of the Pont du Gard (Figure 8) in the 19th century involved the use of new cement mortars to replace eroded stones and stabilize the structure, preventing further erosion and damage (Hauck, 1986). Subsequent interventions in the 20th and 21st centuries, particularly after floods in 1958, 1998, and 2002, required additional consolidation of its pillars and arches. Significant restoration efforts were carried out between 1992 and 2005 in three phases, focusing on structural conservation and flood damage repair (UNESCO, 2006). Today, the Pont du Gard is part of a broader effort to preserve ancient monuments in southern France, including aqueducts proposed for inclusion on UNESCO's tentative list. This nomination covers sites such as Nîmes, Arles, Glanum, and other notable monuments, highlighting the global cultural significance of these structures (UNESCO, 2002).

A similar approach was applied in restoring the historic complex of Split, located in Split, Croatia, including Diocletian's Palace, which is also on UNESCO's tentative list (UNESCO, 2005). This project also encompassed the restoration of Diocletian's Aqueduct, which began in the mid-19th century. Archaeological research conducted in 1855 revealed the advanced skills of ancient surveyors and engineers. In 1999, a section of the aqueduct near Bilice, close to Solin, Croatia**,** was reconstructed while constructing a new road.

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Figure 8. Pillars of Pont du Gard
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These projects emphasize the importance of thorough documentation and the involvement of local experts in conservation efforts, which helps preserve cultural values even when modern approaches are employed. In the case of the aqueduct in Segovia (Figure 9), extensive repairs took place between 1970 and 1974, involving the reinforcement of damaged blocks, stabilization of arches using brass rods, and filling cavities with cement mortar. In 1992, the aqueduct's surface was cleaned using sandblasting to remove deposits and pollutants, with architectural elements strengthened using stainless steel rods. Additionally, contact surfaces were adjusted to redistribute the load more effectively (Schuster, 2016, pp. 14-26).

Despite efforts to maintain authenticity, the use of modern materials such as epoxy resins, in some cases, proved to have undesirable effects, including material degradation and discoloration of masonry, posing new challenges for future restorations. While contemporary materials and methods are sometimes prioritized in restoration, it is crucial to consider these structures' inherent values (Alberts & Hazen, 2010, p. 56–73).

Reports from organizations such as the International Council on Monuments and Sites (ICOMOS) and the International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM) (2021) analyze various approaches to restoration, seeking a balance between using modern technologies to secure the longevity of structures and preserving their authentic elements whenever possible (ICOMOS & ICCROM, 2021). This compromise allows historic structures to meet modern needs while preserving their historical character.

Figure 9. Segovia Aqueduct, Spain
© Rui Vale De Sousa, Dreamstime

Contemporary methods for reconstructing and adapting historic structures, such as concrete injections and steel reinforcements, enable the stabilization of buildings while retaining their historical appearance with materials closely resembling the originals. In Rome, Italy, for instance, the Aqua Claudia restoration project employed a blend of traditional techniques and modern technologies, with reconstructed sections integrated into the Parco degli Acquedotti, allowing these ancient structures to become a part of the contemporary urban environment. This approach aligns with UNESCO's recommendations on integrating cultural heritage preservation into broader development strategies. The 2011 *Recommendation on the Historic Urban Landscape* (HUL) highlights the importance of incorporating cultural heritage conservation into urban planning to balance historical preservation with contemporary needs (UNESCO, 2011).

Historic water systems, such as the Roman aqueduct and cisterns in Ptolemais, Libya, and the Gadara Aqueduct in Jordan, exemplify infrastructure that now contributes to tourism. The Gadara Aqueduct, which linked the ancient Jordanian cities of Gadara (Um Qeis) and Abila (Qweilbeh)—both on UNESCO's Tentative List since 2001 (UNESCO, 2001a, 2001b)—supplied water from springs to these Greco-Roman cultural hubs. Alongside Ptolemais' cistern system, these structures showcase Roman engineering prowess and currently serve as cultural landmarks that attract tourists and bolster local economies. In addition to technical interventions, UNESCO emphasizes environmental and social sustainability in restoration efforts. Reusing historical materials, as was common in constructing these ancient water systems, reduces the need for new resources and protects the environment. Such practices decrease the ecological footprint of restoration projects and strengthen the sense of identity and belonging among local communities, encouraging interest in preserving cultural heritage. Furthermore, modern technologies like 3D scanning and photogrammetry are recommended for accurate monitoring (Tapete et al., 2015), identifying structural deformations, and pinpointing areas that need restoration.

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Conclusions

The examination of ancient aqueducts and qanats reveals their complex legacy as technical marvels and cultural artifacts. While these systems reflect the engineering ingenuity of past civilizations, their preservation today requires addressing various contemporary challenges, from environmental pressures to the decline of traditional knowledge. UNESCO has played a pivotal role in elevating the significance of these systems by recognizing them as part of humanity's shared heritage through initiatives such as the World Heritage Convention. This recognition not only underscores their Outstanding Universal Value (OUV) but also promotes international collaboration, sustainable management, and their integration into modern landscapes. UNESCO's frameworks, such as the Historic Urban Landscape approach, provide critical guidance for balancing preservation with contemporary needs. The examples discussed highlight the diversity of their historical and geographical contexts, underscoring the importance of tailored conservation strategies. Preservation efforts must move beyond merely safeguarding physical structures to consider their broader integration into modern communities. Adaptive reuse, sustainable tourism, and educational initiatives offer opportunities to ensure their relevance, but these approaches must be carefully managed to avoid over-commercialization or loss of authenticity. In particular, the reliance on community-driven stewardship underscores the need to invest in capacity-building and knowledge transfer, ensuring local stakeholders can actively participate in conservation and management.

The preservation of aqueducts and qanats depends significantly on their historical usage and location. Structures that remained in use benefited from regular maintenance and community reliance, preserving their functionality and cultural significance. Abandoned sites, however, often fell into disrepair due to environmental pressures and neglect, leading to structural deterioration and the loss of traditional knowledge. Their restoration requires technical interventions and their reintegration into modern contexts, such as educational programs or heritage initiatives, to maintain their relevance. Location plays a significant role in shaping preservation outcomes. Remote sites, shielded from urban pressures like pollution and overdevelopment, often retain better physical integrity. However, their isolation leaves them vulnerable to neglect and underfunding, as they are less accessible and rarely prioritized. In contrast, aqueducts and qanats situated in urban areas receive more attention and resources due to their visibility and integration into community life. However, urbanization poses risks, including pollution, construction damage, and over-tourism, which can erode their authenticity and stability.

Historical upkeep has played a crucial role in preserving these systems, ensuring their functionality over centuries, while UNESCO's recognition has elevated their cultural and historical importance on a global scale. These factors underscore the importance of balancing traditional maintenance practices with modern heritage management to ensure their continued relevance in contemporary contexts. While these historical adaptations were primarily driven by practical necessity, they inadvertently contributed to preserving these structures. The focus on recreational and tourism-oriented uses has similarly extended their relevance in modern contexts. However, it may also constrain their potential for other innovative applications, such as ecological projects or community-based educational programs. The challenge lies in balancing these modern uses with the need to preserve their authenticity and cultural significance. To further address contemporary challenges, restoration projects should better align with broader environmental objectives, such as water conservation and biodiversity enhancement, to integrate sustainability into heritage management.

Moreover, interdisciplinary collaboration, incorporating insights from sociologists, ecologists, and policy experts, could enhance the socio-cultural integration of restored water heritage in modern settings. These perspectives would broaden the scope of

preservation efforts, ensuring their alignment with environmental and societal priorities. Comparative studies that explore similarities and differences between aqueducts and qanats can yield insights into the broader principles of sustainable water management. Additionally, exploring less-documented cases may reveal alternative preservation methods and innovative adaptations for contemporary use. Ultimately, the long-term survival of these systems depends on a balanced approach that integrates traditional practices with modern technologies while aligning heritage conservation with global sustainability goals. By addressing these challenges through interdisciplinary collaboration and inclusive policies, ancient water systems can continue to provide valuable lessons for managing cultural heritage in the face of evolving environmental and social demands.

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