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The Essential Roles of Qanats on Yazd Sustainable Development as an Improving the Groundwater Productivity: A Review

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Abstract

Introduction: This research examines the multifaceted aspects of Yazd's Qanats, focusing on their infrastructure, environmental and social impact, cultural significance, historic value, preserving effect, and role in shaping the urban landscape. The essential role of Qanats is shaping the landscape, infrastructure, and cultural and social identity of Yazd City, and it needs preservation and integration into sustainable urban planning. Qanats, an ancient water management system, have played a crucial role in sustaining Yazd, a historic city in Iran.

Materials and Methods: The study discusses how the intricate network of tunnels and wells provided by Qanats has reliably supplied water to the city for centuries. It highlights their environmental benefits in reducing water loss through evaporation and preventing groundwater depletion. Qanats' cultural and heritage aspects are explored, emphasizing their contribution to Yazd's identity as architectural and engineering marvels. Furthermore, examines their influence on the city's layout and architectural design. Also, addressing the challenges and threats faced by Yazd's Qanats despite their historical and cultural significance. Rapid urbanization, changes in water management practices and diminishing maintenance efforts have endangered these ancient water systems. Recognizing and addressing these challenges is crucial to ensure the sustainability and preservation of Yazd's Qanats for future generations. The methodology employed for this review study is outlined

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in this part. A comprehensive literature review incorporated academic papers, historical records, and cultural studies. Data about Qanats' infrastructure, environmental impact, social aspects, cultural significance, and historical context in Yazd were collected and analyzed. Site visits to Qanat structures and interviews with local experts and community members provided valuable first-hand insights and perspectives.

Results: The conclusion drawn from the review study emphasizes the essential roles played by Yazd's Qanats in ensuring the city's sustainability. Preserving and protecting these ancient water systems is crucial due to their significance in water resource management, cultural heritage, and urban planning. The paper concludes by calling for increased awareness, conservation measures, and policy support to ensure Yazd's Qanats' continued existence and functionality, contributing to the city's overall sustainability.

Conclusions: Raising public awareness about Qanats' cultural, historical, and environmental significance is vital for their preservation. Educational programs and awareness campaigns can help foster a sense of pride and responsibility among the local community, promoting their active involvement in the conservation and maintenance of these ancient water systems. Exploring adaptive reuse strategies and innovative approaches can contribute to the sustainable utilization of Qanats. By integrating modern technologies and practices while respecting traditional methods, Qanats can continue to play a vital role in water management, adapting to the changing needs and demands of the community. Active engagement and collaboration among stakeholders, including local communities, experts, authorities, and organizations, are essential for Qanats' preservation and sustainable management. Through collective efforts, knowledge sharing, and collaboration, the challenges faced by these ancient water systems can be addressed effectively. Considering these criteria, Yazd's Qanats can be preserved and protected, ensuring their continued contribution to sustainability. Recognition and legal protection, integrated planning approaches, hydrological and environmental considerations, public awareness and education, adaptive reuse and innovation, and stakeholder engagement and collaboration are key to safeguarding these remarkable water systems' cultural, historical, and environmental significance. Through these collective efforts, the legacy of Yazd's Qanats can be preserved for future generations, fostering sustainable development and ensuring the city's water security and cultural heritage.

Keywords: Qanats, Aquifer, Cities' landscape, Urban infrastructure, Cultural significance, Social significance, Urban planning, Water scarcity, Sustainable development, Groundwater.

1. Introduction

Water scarcity is a significant challenge facing many regions worldwide, particularly in arid areas (Zamani et al., 2021). One of the unique solutions to this challenge is using Qanats, underground aqueducts that have been utilized for centuries to provide water for agricultural and urban areas. Yazd, located in central Iran, has a long history of qanat usage. The city's reliance on this system has shaped its landscape, infrastructure, and cultural and social identity. As a result, understanding the role of Qanats in shaping the urban development of Yazd is crucial for promoting sustainable development, preserving cultural heritage, and creating a more resilient city. This paper aims to explore the essential role of Qanats in shaping the landscape and culture of Yazd City from a sustainable and cultural perspective. Through a literature review of previous studies and case studies of Yazd City, this paper highlights the historical and cultural significance of Qanats in shaping the urban landscape of Yazd, providing a sustainable solution to water scarcity, and influencing the city's cultural and social identity. Furthermore, this paper emphasizes the need to preserve Qanats as an integral part of Yazd City’s cultural and historical heritage and integrate them into sustainable urban planning. The findings of this study can provide insights for policymakers, planners, and stakeholders to develop strategies that integrate Qanats into urban planning, promote sustainable development, and preserve cultural heritage in arid regions.

2. Statement of Issue

The essential role of Qanats is shaping the landscape, infrastructure, and cultural and social identity of Yazd City, and it needs preservation and integration into sustainable urban planning. The paper aims to explore the historical and cultural significance of Qanats in shaping the urban landscape of Yazd, providing a sustainable solution to water scarcity, and influencing the city's cultural and social identity. The study highlights the importance of preserving Qanats as an integral part of Yazd city's cultural and historical heritage and integrating them into sustainable urban planning to promote sustainable development, preserve cultural heritage, and create a more resilient city.

3. Overview

The history of Qanats in Iran dates back over two thousand years. The technology of Qanats spread throughout the country and was particularly

important in Yazd. The city has a rich history of qanat usage, and the system has played an essential role in shaping the city's landscape and culture. Qanats have provided the primary water source for the town and surrounding areas, enabling agriculture and urban development. The construction of Qanats required a significant investment of time, labor, and resources, and their maintenance and operation required a collective effort from the community. Thus, Qanats not only provided a vital resource but also contributed to the social and cultural identity of Yazd (Semsar Yazdi, 2018).

The importance of Qanats in shaping the infrastructure and urban development of Yazd cannot be overstated. The city's urban form was designed around the qanat system, with neighborhoods and public spaces clustered around qanat heads, known as 'badgers' or wind towers. The towers provided natural ventilation and cooling for buildings, and their design reflects the city's architectural heritage. Qanats also influenced the city's transportation system, with narrow alleys and streets designed to accommodate the movement of people, animals, and water. Integrating Qanats into the city's infrastructure and urban form highlights their importance as a sustainable and cultural solution to water scarcity.

Qanats represent a sustainable solution to water scarcity utilized for centuries in Yazd. The system relies on gravity and natural filtration to deliver water without energy inputs or emissions. Additionally, Qanats are resistant to drought and climate change, making them an essential resource for arid regions. However, the decline in qanat usage in recent years due to modernization and urbanization has led to significant challenges for Yazd's water supply. The preservation and promotion of Qanats as a sustainable solution to water scarcity are crucial for the future of Yazd and other arid regions.

The preservation of Qanats is also essential for preserving the cultural heritage of Yazd. Qanats have played a significant role in shaping the city's identity and have been celebrated in art, literature, and music. The system also reflects the ingenuity and skill of traditional Iranian engineers and artisans. Therefore, preserving and promoting Qanats as a cultural heritage asset can contribute to the city's tourism industry and provide economic benefits.

4. Methodology

Qualitative methods could gather data on the historical and cultural significance of Qanats in Yazd City and their role in shaping its landscape and cultural identity. This could involve interviews with residents, experts, and

stakeholders with knowledge and experience with Qanats and their impact on the city. It could also include reviewing archival documents, photographs, and historical records related to the region's construction and use of Qanats.

Quantitative methods could be used to analyze data on Qanats' environmental and social benefits as a sustainable water management solution in arid regions. This could involve collecting data on water usage, energy consumption, and cost savings associated with qanat systems compared to other water management strategies. It could also include analyzing data on community participation and engagement in water management practices related to Qanats.

Additionally, the study could include a literature review to gather information on the historical and cultural significance of Qanats in the region and their environmental and social benefits. The study could also involve site visits to observe the Qanats and their role in shaping the landscape of Yazd City. Overall, the research method would aim to provide a comprehensive and integrated understanding of the essential role of Qanats in shaping the landscape and culture of Yazd City.

5. Literature Review

The research background is based on several areas of study, including history, culture, environmental sustainability, and urban planning. This section will provide an overview of the research backgrounds related to these areas of study and their relevance to the article.

The history of Qanats is rooted in ancient Persia, where the first Qanats were constructed over 3000 years ago. Qanats were crucial in developing cities and civilizations in arid regions, including Iran, Egypt, and China. As a result, the history of Qanats is a significant area of study in archaeology, anthropology, and history. Researchers have explored the construction, management, and cultural significance of Qanats and their impact on the development of cities and civilizations in arid regions (Semsar Yazdi, 2018).

Qanats have played a vital role in shaping the cultural identity of Yazd City and other regions in Iran. The cultural significance of Qanats is rooted in their values of community, cooperation, and sustainability (Ehteshami et al., 2015). The study of culture is essential in understanding the role of Qanats in shaping the landscape and identity of Yazd City, as well as the challenges and opportunities associated with their preservation and utilization.

Using Qanats as a sustainable water management solution in arid regions

has been the subject of environmental science, hydrology, and water management research. Qanats are considered an environmentally sustainable solution to water scarcity, as they rely on gravity to transport water, reducing energy consumption and greenhouse gas emissions associated with pumping water from underground sources. The study of Qanats as a sustainable solution to water scarcity is essential in understanding their potential as a tool for environmental sustainability and mitigating the impacts of climate change.

The integration of Qanats into urban planning strategies is a significant area of research in the field of urban planning. The preservation and utilization of Qanats in urban areas require a comprehensive and participatory approach that involves stakeholders, policymakers, and planners in addressing the challenges and opportunities of integrating this ancient water management system into modern urban infrastructure. The study of Qanats in the context of urban planning is essential in understanding their potential as a tool for sustainable urban development and enhancing the cultural identity of cities.

In summary, the research background is rooted in several areas of study, including history, culture, environmental sustainability, and urban planning. The study of Qanats in these areas has provided valuable insights into their historical and cultural significance, their potential as a sustainable solution to water scarcity, and their role in shaping the landscape and identity of cities. The article aims to integrate these different research backgrounds to provide a comprehensive and integrated understanding of the essential role of Qanats in shaping the landscape and culture of Yazd City.

6. Examining the Features and Characteristics of Qanats

6-1. Yazd's Qanats

Yazd, located in central Iran, is known for its historical Qanats, underground water channels used for irrigation, and water supply. Some of the main Qanats in Yazd City are:

A) Qanat-e Zarch: This is one of the most famous Qanats in Yazd and is considered the longest Qanat in the world. It stretches for about 80 kilometers and has been used for over 2,500 years. Qanat-e Zarch has played a significant role in providing water for agriculture and sustaining the city's population.

B) Qanat-e Mullah Ismail: This Qanat is named after Mullah Ismail, a prominent religious figure who played a crucial role in its construction. Qanat-e Mullah Ismail is known for its architectural features, including windcatchers (Badgir), ventilated, and excellent underground channels (UNESCO, n.d.).

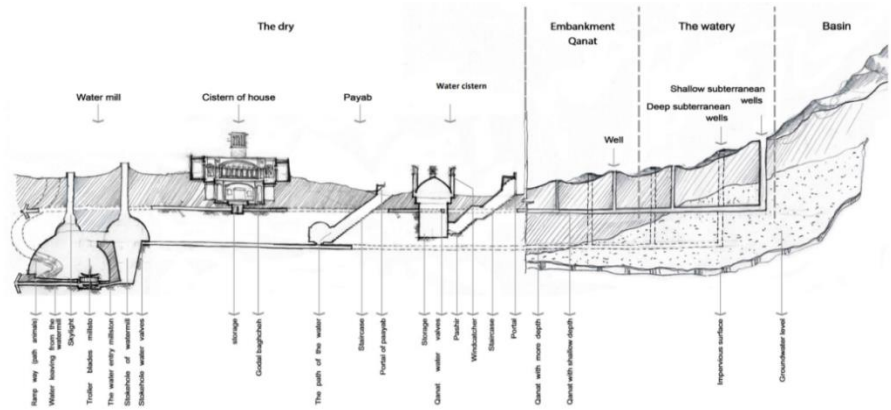

Fig. 1. Figurate section of the Qanat and its relationship with the city's building -adapted from the global registration of Iranian Qanats at UNESCO (Iranian Cultural Heritage, Handicrafts and Tourism Organization, 2016)

C) Qanat-e Fahraj: Located in the Fahraj district of Yazd, this Qanat is known for its intricate engineering and is considered one of the oldest Qanats in the region. It has been supplying water to the surrounding areas for centuries and remains a vital water source (Choubineh, 2014).

D) Qanat-e Haj Agha Ali: This Qanat is named after Haj Agha Ali, a resident who played a significant role in its construction. Qanat-e Haj Agha Ali is known for its efficient water distribution system, which has helped irrigate farmlands and gardens in the area (Khorshidi, 2011).

These are just a few examples of the main Qanats in Yazd City. The city is renowned for its extensive underground water channels, and many other Qanats have contributed to the region's water management and agricultural practices throughout history.

6-2. Qanats's Effect on Shaping the Urban Landscape

Qanats have played a significant role in shaping the urban formation of Yazd City. They have influenced various city development aspects, including settlement patterns, architectural features, and water management strategies.

The presence of Qanats in Yazd has influenced the location and layout of settlements. The Qanats provided a reliable water source, allowing people to establish communities where water was scarce. As a result, the city's development followed the path of these underground channels, with neighborhoods and buildings clustered around Qanat access points (Vahabzadeh, 2016).

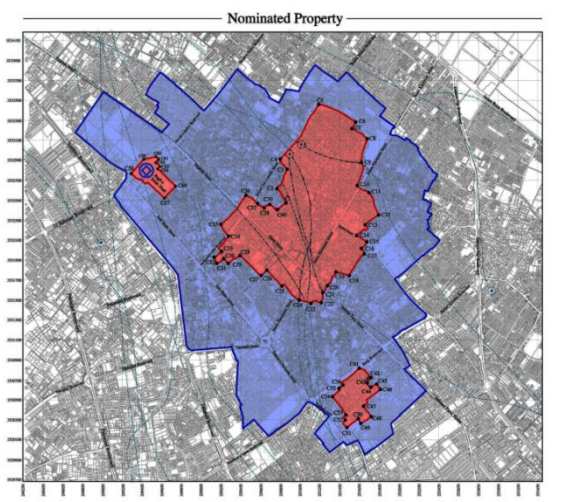

Fig. 2. Qanats in The route of the Qanats in the historical context of Yazd (Iranian Cultural Heritage, Handicrafts and Tourism Organization, 2016)

The Qanats have influenced the architectural features of Yazd City. One notable example is the presence of wind catchers (Badgir), which are traditional ventilation structures found on rooftops. The Qanats supplied water for evaporative cooling systems, integrated with wind catchers to create a natural cooling effect in buildings (UNESCO, n.d.). This architectural adaptation to the Qanat system has helped to mitigate the extreme desert climate in Yazd.

The Qanats have shaped the water management strategies employed in Yazd. The Qanat system allowed for the efficient distribution and utilization of water resources. The underground channels channeled water from distant sources to the city, ensuring a steady water supply for various purposes, including domestic use, irrigation, and agricultural activities (Khalili et al., 2017). The management and maintenance of the Qanats required community collaboration and expertise, which fostered a sense of communal responsibility and shared water governance. The roles of Qanats in shaping Yazd's urban formation are evident in the city's settlement patterns, architectural elements, and water management strategies. The integration of Qanats into the city’s fabric has been instrumental in creating a sustainable and resilient urban environment.

6-3. Qanats Preserving Effects

Preserving and promoting Qanats as a cultural heritage asset can significantly impact a city's tourism industry and provide various economic benefits. By

highlighting Qanats' historical and cultural significance, tourism can be enhanced, attracting visitors and generating economic opportunities for the local community.

Preserving Qanats as cultural heritage sites can attract tourists interested in exploring unique historical and architectural features. Qanats represent an ancient and remarkable engineering feat, showcasing the ingenuity and craftsmanship of past civilizations (Yazd Cultural Heritage, Handicrafts, and Tourism Organization, n.d.). Tourists keen on history, architecture, and cultural heritage will likely visit the city to witness these remarkable water systems firsthand.

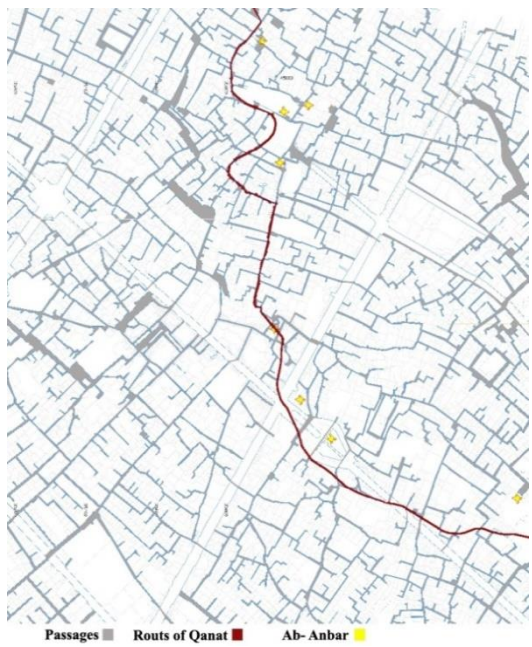

Fig. 3. The Route of Zarch Qanat in the historical context of Yazd and its Effect on city formation (**Source:** Authors)

Promoting Qanats as a cultural attraction can diversify the tourism offerings of a city, expanding its appeal beyond conventional destinations. Visitors are drawn to experiences that provide insights into local traditions and heritage, and Qanats offer a glimpse into the historical water management practices of the region (Yazd Cultural Heritage, Handicrafts, and Tourism Organization, n.d.). This unique aspect can differentiate the city from other tourist destinations and attract a niche market of cultural and heritage enthusiasts.

The presence of well-preserved Qanats can also contribute to developing cultural tourism infrastructure in the city. Supporting facilities such as visitor centers, museums, guided tours, and interpretation sites can be established to provide educational and immersive experiences for tourists (Nabavi & Zare, 2016). This infrastructure development not only enhances the visitor experience but also generates employment opportunities for local communities, contributing to the economic growth of the tourism sector.

Furthermore, Qanats can catalyze the development of other tourism-related businesses. Tourists visiting Qanats create a demand for accommodation, restaurants, transportation services, and handicraft shops in the vicinity (Nabavi & Zare, 2016). Local entrepreneurs can capitalize on this demand by establishing businesses catering to tourists' needs and preferences, leading to job creation and income generation.

The economic benefits extend beyond the immediate tourism sector. The preservation and promotion of Qanats can stimulate the growth of related industries, such as traditional crafts and cultural events. Artisans specializing in handicrafts inspired by Qanats, such as pottery, carpet weaving, or traditional clothing, can find a market among tourists seeking authentic souvenirs (Nabavi & Zare, 2016). Additionally, cultural events and festivals celebrating Qanats can attract visitors, generating revenue for local businesses and communities.

In conclusion, preserving and promoting Qanats as a cultural heritage asset can contribute significantly to the tourism industry and provide economic benefits to the city. By attracting tourists interested in history and cultural heritage, Qanats diversify tourism offerings and create opportunities to develop tourism-related infrastructure and businesses. The economic benefits extend to related industries, stimulating local craftsmanship and cultural events. The preservation and promotion of Qanats as a cultural heritage asset safeguard the city’s historical legacy and contribute to its economic growth and community well-being.

6-4. Historic Significance

Qanats in Yazd City hold immense historical significance, pivotal in shaping its landscape and cultural identity. The development of Qanats dates back over two millennia, with evidence suggesting their presence in the region since the Achaemenid Empire (6th century BCE) (Yazd Cultural Heritage, Handicrafts, and Tourism Organization, n.d.). These subterranean water channels transformed the arid desert into a habitable and agriculturally productive area,

leading to the establishment and growth of settlements in Yazd City.

The engineering and construction of Qanats required advanced knowledge and expertise. Skilled craftsmen and engineers developed sophisticated techniques for locating water sources, excavating tunnels, and maintaining the channels. The innovation and mastery of qanat technology in Yazd City contributed to the growth and prosperity of the region (Nabavi & Zare, 2015).

Moreover, Qanats have left an indelible mark on the landscape of Yazd City. The physical presence of these underground water channels has shaped the urban planning, architecture, and infrastructure of the city. Above-ground features such as well towers, access points, and distribution structures are integrated into the urban fabric, serving as distinct landmarks and reflecting the reliance of the community on the qanat system (Mehran & Taleghani, 2015).

In addition to their practical importance, Qanats hold deep cultural significance for the people of Yazd City. They are an integral part of the local heritage and have become symbols of community identity and pride. The reliance on Qanats has given rise to a unique set of social and cultural practices, including water-sharing customs, communal maintenance efforts, and storytelling traditions centered around the qanat system (Nabavi & Zare, 2016).

Qanats have also inspired artistic and literary expressions, influencing local folklore, poetry, and music. The cultural significance of Qanats in Yazd City is further underscored by their representation in traditional architecture, handicrafts, and festivals, contributing to the city's intangible cultural heritage (Nabavi & Zare, 2016).

In conclusion, Qanats have played a vital role in shaping the historical, physical, and cultural aspects of Yazd City. They have enabled sustainable water management, facilitated agricultural development, and provided the foundation for human settlement in the desert region. The recognition of Qanats by UNESCO as an integral part of Yazd City's World Heritage Site status further emphasizes their historical significance and underscores the need for their preservation.

Qanats have a historical significance in Yazd City, as they are the oldest and most extensive underground water channels in the world, dating back to about 3,000 years ago. Qanats have enabled the development and survival of Yazd, a historical city in the deserts of Iran, for thousands of years. Qanats have shaped the historic landscape, architecture, and culture of Yazd, creating a unique and valuable heritage recognized by UNESCO as a World Heritage Site.

Qanats offer several environmental and social benefits as a sustainable solution to water scarcity in arid regions. By harnessing and managing groundwater resources, Qanats contribute to groundwater conservation and sustainable water supply. Their integration into sustainable development strategies can further enhance these benefits.

From an environmental perspective, Qanats help conserve precious water resources in arid regions. By tapping into underground aquifers, they enable the extraction and utilization of groundwater while minimizing water loss due to evaporation and surface runoff (Angelakis et al., 2017; Naderi et al., 2014). This efficient water management reduces strain on surface water sources and promotes the sustainability of water supplies in arid environments.

Qanats also mitigate the environmental impacts associated with alternative water extraction methods such as pumping from deep wells. Unlike pumping, which can lead to the depletion of aquifers and land subsidence, Qanats maintain a balanced groundwater level, preventing over-extraction and preserving the overall hydrological equilibrium (Naderi et al., 2014).

Moreover, Qanats contribute to microclimate regulation and the promotion of biodiversity. As water flows through the underground channels, it cools down, reducing the surrounding air temperature and creating localized microclimates supporting vegetation growth in arid regions (Naderi et al., 2014). These microclimates and vegetation near Qanats make habitats for various plant and animal species, fostering biodiversity conservation (Kapupara et al., 2023).

On the social front, Qanats provide reliable and sustainable water sources for communities in arid regions. They ensure a consistent water supply throughout the year, even during drought or water scarcity (Nabavi & Zare, 2015). This stability in water access enhances food security, supports agricultural livelihoods, and contributes to the overall well-being of communities.

Furthermore, Qanats foster social cohesion and community involvement. The communal management and maintenance of Qanats require collective efforts, encouraging cooperation and shared responsibility among community members (Nabavi & Zare, 2016). Water-sharing customs and traditions associated with Qanats promote social interactions and strengthen community bonds.

Integrating Qanats into sustainable development strategies involves recognizing their potential and incorporating them into water management plans and policies. Governments and relevant stakeholders can prioritize the restoration and preservation of existing Qanats, ensuring their functionality and

longevity. Additionally, new qanat construction projects can be undertaken in suitable locations to expand water supply options in arid regions.

Investments in qanat infrastructure, such as well towers, access points, and distribution systems, can enhance efficiency, reduce water loss, and optimize water distribution. Implementing modern technologies and innovative approaches can further improve qanat systems, such as sensor networks for Monitoring water flow, filtration systems to ensure water quality and sustainable energy solutions for pumping water into the qanat system. Raising awareness and promoting education about the value and benefits of Qanats are crucial. Communities, policymakers, and relevant institutions can engage in capacity-building initiatives, knowledge sharing, and cultural preservation efforts to ensure the continuity of Qanats as sustainable water management systems.

6-5. Qanats's effects on culture and heritage

Qanats play significant roles in the culture and heritage of Yazd, contributing to its identity as a unique and historical city.

Qanats have shaped cultural practices and traditions in Yazd. They have been a focal point for community gatherings and social interactions, fostering a sense of belonging and unity among the residents. The shared responsibility of maintaining and operating Qanats has created a strong community bond, promoting cultural heritage and local knowledge transmission (UNESCO, n.d.).

The Qanats of Yazd, including Qanat-e Zarch, have been recognized by UNESCO as part of the Yazd Historic City World Heritage Site. The inscription acknowledges the outstanding universal value of Qanats as an exceptional example of human ingenuity in harnessing natural resources and managing water sustainably (UNESCO, n.d.).

These roles collectively contribute to Qanats' cultural and heritage significance in Yazd, showcasing the city's rich history, traditional practices, and unique architectural heritage.

6-6. Qanats's effect on environmental and social

By integrating Qanats into sustainable development strategies, arid regions can achieve multiple objectives, including water security, environmental conservation, and social well-being. Qanats have several environmental and social benefits as a sustainable solution to water scarcity in arid regions. Firstly, they reduce the dependence on fossil fuels and greenhouse gas emissions by utilizing gravity and natural energy to transport water without the

need for pumps or electricity (Abbaspour & Kavianpour, 2021). Secondly, Qanats preserve groundwater quality and quantity by tapping into aquifers at sustainable rates and preventing salinization and depletion (Asadi & Asadi, 2017). Additionally, Qanats enhance the biodiversity and productivity of ecosystems by creating green oases of vegetation, supporting wildlife, and promoting agriculture and food security (Alizadeh & Pourjafar, 2019; Bakhtiar, 2020). Moreover, Qanats contribute to the promotion of cultural and natural heritage, reflecting ancient wisdom and human-nature interactions and being associated with sacred values and beliefs (Alipour et al., 2021; Daneshpour et al., 2021b). They also foster social cohesion and empowerment by requiring collective action and cooperation among local communities that share and manage water resources through traditional institutions and practices (Asadi & Asadi, 2017; Ghorbanzadeh & Roshan, 2018).

To integrate Qanats into sustainable development strategies, several approaches can be adopted. This includes supporting research and innovation on qanat technology and management while disseminating best practices and lessons learned across regions and countries (Ehteshami et al., 2015). Conservation and restoration efforts are essential to address challenges posed by climate change, urbanization, groundwater over-exploitation, pollution, and neglect (Bakhtiar, 2020; Daneshpour et al., 2021a). Raising public and policy maker awareness and involvement in qanat-related projects and initiatives is crucial (Alizadeh & Pourjafar, 2019). Moreover, economic opportunities and incentives for qanat users and stakeholders, such as eco-tourism, carbon offsetting, water pricing, and endowment, can be developed.

6-7. Qanats Role as an infrastructure

The presence of Qanats has significantly influenced the infrastructure and urban development of Yazd City, showcasing the integration of water management into the urban fabric. The location and design of infrastructure in Yazd City are dictated by the underground channels of Qanats. Well towers, known as Badgirs or windcatchers, have been constructed to access underground water sources, serving as functional elements for drawing air into buildings and contributing to the city's skyline (Eskandar et al., 2022). The planning of neighborhoods and streets in Yazd City follows the paths of Qanats, ensuring easy access to water sources for the community through traditional buildings designed to capture and conserve water efficiently, such as underground storage tanks (ab-anbars) and water distribution systems (Nabavi & Zare, 2016).

This integration of Qanats into the urban fabric of Yazd City has implications for sustainable urban planning. It reduces the carbon footprint associated with water distribution by relying on a gravity-based water supply system instead of energy-intensive pumping (Naderi et al., 2014). Traditional underground storage tanks help regulate water temperature, reducing energy requirements for cooling during hot summers. Qanats also promote water conservation and land use by encouraging efficient irrigation practices, minimizing water wastage, and ensuring sustainable agricultural production (Nabavi & Zare, 2015).

Furthermore, integrating Qanats into the urban landscape of Yazd City contributes to its cultural heritage and sense of place. By preserving and incorporating these historical elements, the city maintains its unique identity and cultural continuity (Mehran & Taleghani, 2015). This approach to urban planning recognizes the importance of heritage preservation and the contribution of traditional systems to the city's social fabric.

The Qanat system has significantly influenced the infrastructure and urban development of Yazd City in multiple ways. Firstly, it has provided a reliable and sustainable source of water for various purposes, including drinking, irrigation, industry, and public services, which is particularly vital in the city's desert environment characterized by scarce rainfall and high evaporation (Abbaspour & Kavianpour, 2021; Ehteshami et al. 2015). Additionally, the qanat system has shaped the unique historic landscape of Yazd, with distinct features such as conical mounds marking the good shafts, green oases of gardens and farms, and underground water cisterns (Madadi et al., 2022; Abbaspour & Kavianpour, 2021; Abedi & Eftekhar, 2017; Alizadeh & Pourjafar, 2019). This historic landscape is further reflected in the earthen architecture of Yazd, characterized by courtyards, wind-catchers, vaults, and domes, all of which optimize water use and create a pleasant microclimate (Abedi & Eftekhar, 2017; Eskandar et al., 2022). Moreover, the qanat system has fostered a culture of cooperation and solidarity among local communities who share and manage the water resources through traditional institutions and practices, thereby contributing to social cohesion and community resilience (Asadi & Asadi, 2017; Daneshpour et al., 2021a).

Furthermore, the qanat system has implications for sustainable urban planning in Yazd. Firstly, it plays a crucial role in preserving the city's cultural and natural heritage, as evidenced by its designation as a World Heritage Site. The Qanats raise awareness about the value and significance of Yazd's heritage, highlighting the need for their conservation and protection (Alipour

et al., 2021; Ghorbanzadeh & Roshan, 2018). Additionally, the revival of the Qanats offers opportunities for tourism development, providing a source of income and attraction while ensuring their sustainable management and preservation (Bakhtiar, 2020; Daneshpour et al. 2021b). Moreover, the qanat system promotes the participation and empowerment of local stakeholders in decision-making processes and the implementation of qanat-related projects, ensuring that their voices are heard and their needs are met (Daneshpour et al., 2021a). Finally, the qanat technology and wisdom serve as a valuable model for water management and urban development, offering lessons that can be adapted to the local context and environment of Yazd (Asadi & Asadi, 2017; Ehteshami et al., 2015).

In conclusion, the qanat system has profoundly influenced the infrastructure and urban development of Yazd City. The presence of Qanats has shaped the city's layout, architectural elements, and infrastructure, contributing to its distinctive identity. Integrating Qanats into the urban fabric holds implications for sustainable urban planning by promoting resource efficiency, water conservation, and cultural heritage preservation. The qanat system provides a reliable water supply, regulates temperature, promotes efficient land use, and fosters social cohesion. Additionally, it preserves the city's cultural and natural heritage, offers economic opportunities, and serves as a model for water management. By recognizing the importance of Qanats, Yazd City can ensure a sustainable and resilient future while preserving its unique identity and sense of place.

7. Discussion

Qanats are a remarkable example of human ingenuity and resilience in harsh environmental challenges. For thousands of years, they have enabled the development and survival of Yazd, a historic city in the deserts of Iran. Qanats have shaped the historic landscape, architecture, and culture of Yazd, creating a unique and valuable heritage that deserves recognition and preservation. Qanats also offer lessons and inspiration for sustainable water management and urban development in the present and future.

Addressing the challenges and opportunities for preserving and integrating Qanats into sustainable urban planning requires a collaborative effort among policymakers, planners, and stakeholders. The following aspects can be addressed effectively by implementing appropriate strategies and measures.

A) Recognition and Legal Protection: Policymakers can establish legal frameworks and regulations recognizing Qanats as valuable cultural and

environmental assets and designing Qanats as protected heritage sites to ensure their preservation and prevent encroachment or destruction during urban development (Alipour et al., 2021). This recognition provides a foundation for integrating Qanats into urban planning processes.

B) Integrated Planning Approaches: Urban planners should adopt an integrated approach that considers Qanats integral components of the urban fabric. Incorporating Qanats into land-use plans, zoning regulations, and infrastructure development, plans ensure their inclusion in the overall urban framework (Alipour et al., 2021). Coordination between water management, heritage preservation, and urban planning departments is crucial to this integration.

C) Hydrological and Environmental Considerations: Sustainable urban planning should prioritize the preservation and sustainable use of water resources associated with Qanats. Developing water management strategies that consider the recharge, maintenance, and protection of Qanats' underground aquifers is essential (Bakhtiar, 2020). Assessing the environmental impacts of urban development on Qanats, such as land subsidence or pollution, is also essential for their preservation and sustainability (Bakhtiar, 2020).

D) Public Awareness and Education: Stakeholders play a vital role in preserving Qanats. Public awareness campaigns and educational programs can increase the understanding and appreciation of Qanats among local communities, policymakers, and planners. By fostering a sense of ownership and pride, stakeholders are more likely to participate in the preservation and integration efforts actively (Alipour et al., 2021).

E) Adaptive Reuse and Innovation: Qanats can be integrated into sustainable urban planning through adaptive reuse and innovative approaches. Identifying opportunities to repurpose Qanats for alternative uses, such as water supply for urban parks or green spaces, can enhance their value and sustainability (Bakhtiar, 2020). Applying modern technologies, such as sensor networks or remote sensing, to monitor and manage qanat systems can also improve their efficiency and effectiveness (Bakhtiar, 2020).

F) Stakeholder Engagement and Collaboration: Engaging stakeholders, including local communities, heritage organizations, academic institutions, and private sector entities, fosters collaboration and shared responsibility in preserving and integrating Qanats. Stakeholder consultations, partnerships, and involvement in decision-making ensure that diverse perspectives are considered, and collective actions are taken toward sustainable urban planning (Alipour et al., 2021).

A multidimensional and participatory approach is necessary to address the challenges and opportunities for qanat preservation and integration into sustainable urban planning. By recognizing Qanats' cultural, environmental, and socio-economic value, policymakers, planners, and stakeholders can work together to safeguard these unique heritage assets while incorporating them into sustainable urban development.

Policymakers, planners, and stakeholders can address the challenges and opportunities for preserving and integrating Qanats into sustainable urban planning by taking several key actions. First, it is crucial to recognize the value and significance of Qanats as a cultural heritage asset and a sustainable water system. This recognition should be incorporated into urban policies, plans, and regulations to ensure their protection and inclusion in future developments. Second, supporting research and innovation on qanat technology and management is essential. By disseminating best practices and lessons learned among different regions and countries, knowledge sharing can enhanced and adoption of sustainable qanat management strategies cand be fostered (Ahmadi, 2019). Third, investing in the conservation and restoration of Qanats is vital. Climate change, urbanization, groundwater over-exploitation, pollution, and neglect pose significant challenges and threats to these ancient water systems. Taking measures to address these issues is crucial for their long-term sustainability (World Bank, 2020). Additionally, raising public awareness and appreciation of Qanats among the general public and policymakers is essential. It can be ensured that their participation and engagement by involving them in Qanat-related projects and initiatives (Ahmadi, 2019). Moreover, creating economic opportunities and incentives for qanat users and stakeholders, such as eco-tourism, carbon offsetting, water pricing, and endowment, can further motivate their preservation and integration into urban planning. Finally, promoting the integration of Qanats with other aspects of sustainable urban planning, such as green infrastructure, nature-based solutions, circular economy, and urban food systems, can lead to more holistic and resilient urban environments (UNEP, 2019). By taking these steps, Qanats can successfully be preserved and integrated into sustainable urban planning, benefiting current and future generations.

8. Conclusions

In conclusion, this review study has examined the multifaceted aspects of Yazd's Qanats and their essential roles in ensuring sustainability. Based on the findings, some criteria are crucial for preserving and protecting these ancient

water systems. Recognizing Yazd's Qanats' cultural and historical significance through legal frameworks and official designations is imperative. These invaluable heritage structures can be safeguarded from encroachment and destruction by providing legal protection. Incorporating Qanats into integrated planning approaches is essential for their sustainable management. By considering their hydrological and environmental implications, comprehensive water management strategies can be developed to optimize their use, ensuring long-term water supply reliability and mitigating the impacts of climate change. Evaluating Qanats' hydrological and environmental aspects is crucial for sustainable water resource management. Recognizing their ability to reduce the water loss through evaporation and prevent groundwater depletion should inform decision-making processes to ensure responsible and efficient water use. Raising public awareness about Qanats' cultural, historical, and environmental significance is vital for their preservation. Educational programs and awareness campaigns can help foster a sense of pride and responsibility among the local community, promoting their active involvement in the conservation and maintenance of these ancient water systems. Exploring adaptive reuse strategies and innovative approaches can contribute to the sustainable utilization of Qanats. By integrating modern technologies and practices while respecting traditional methods, Qanats can continue to play a vital role in water management, adapting to the changing needs and demands of the community. Active engagement and collaboration among stakeholders, including local communities, experts, authorities, and organizations, are essential for Qanats' preservation and sustainable management. Through collective efforts, knowledge sharing, and collaboration, the challenges faced by these ancient water systems can be addressed effectively.

Considering these criteria, Yazd's Qanats can be preserved and protected, ensuring their continued contribution to sustainability. Recognition and legal protection, integrated planning approaches, hydrological and environmental considerations, public awareness and education, adaptive reuse and innovation, and stakeholder engagement and collaboration are key to safeguarding these remarkable water systems' cultural, historical, and environmental significance. Through these collective efforts, the legacy of Yazd's Qanats can be preserved for future generations, fostering sustainable development and ensuring the city's water security and cultural heritage.

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