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REVIEW

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Comprehensive classification and categorization of Qanat features: an interdisciplinary exploration using landscape infrastructure concept and semi-systematic review

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Abstract

Qanats, as traditional and intelligent water infrastructures, have garnered attention across various scientific disciplines. However, a comprehensive, holistic view of Qanats remains elusive. This study aims to identify and present a thorough perspective on Qanat features. To achieve this objective, a semi-systematic review methodology was employed. The semi-systematic or narrative review approach is well-suited for subjects that span multiple disciplines and different periods. The research process commenced with an extensive search for the keyword "Qanat" within the titles and abstracts of articles across the MagIran, ScienceDirect, Taylor and Francis, and Springer databases. Subsequently, a thematic content analysis method was applied to analyze the content of these articles. Thematic content analysis involves the identification and presentation of recurring patterns in the form of distinct themes within the textual data. At this stage, Qanat features were extracted from the articles and categorized thematically. The research findings underscore the functional significance of Qanats as vital water supply systems. Furthermore, within the realm of management, Qanats are recognized as essential water infrastructures. In light of these findings, this study incorporates relevant literature from the infrastructure domain to systematically categorize Qanat features. In the research, the Landscape approach, characterized by its objective-subjective perspective, will serve as an overarching narrative framework to comprehensively classify all Qanat features. The resulting model portrays Qanats as possessing a diverse spectrum of tangible and intangible attributes, spanning environmental, cultural, social, and economic domains. This comprehensive analysis enhances our understanding of the multifaceted nature of Qanats, facilitating their preservation and sustainable management.

Keywords Qanat, Qanat features, Infrastructure, Landscape infrastructure, Landscape approach

Introduction

A Qanat is a traditional water supply system and a valuable cultural heritage. Some scholars believe that the invention of Qanats dates back to around 6000 years ago, while others trace it to the time of the Achaemenids (Sedghi and Jan 2020; Delfani et al. 2021). The Qanat is essentially a horizontal well that extracts water from aquifers and conveys it from hills to the surface of the earth through gravity alone. The Qanat also consists of

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some interconnected shaft wells that are vital for maintenance as well as ventilation (Labbaf Khaneiki 2019) (See Fig. 1).

In addition, the Qanat is a multi-layered water distribution system that carries significant environmental, social and cultural value.

For instance, Qanats influence the the organic carbon content by increasing soil moisture. (Bagwan et al. 2003). Or playing a role in sociocultural communication through its unique water management network (Fadakar Davarani 2009; Fadakar Davarani and Samaraam 2018; Labbaf Khaneiki 2019).

Unfortunately, in the modern era, Qanats have been replaced by more contemporary water infrastructure such as deep wells and piped water systems (Alhashemi 2021). Today, discussions about reviving Qanats arise for two reasons: water crises and cultural preservation.

However, the one-dimensional modern perspective that led to the neglect and deterioration of Qanats cannot be employed in their revival. For instance, in the Mehrgerd Qanat revival project in Tehran, a technocratic approach focused solely on restoring the Qanat structure, utilizing it for urban green space irrigation. Similarly, in the Kish Qanat revival project, a one-sided approach emphasized the historical and cultural values of Qanats, turning them into underground museums.

This one-dimensional perspective in Qanat revival projects stems from a one-dimensional view of Qanats in research. Consequently, there is a gap in research literature for a holistic portrayal of Qanats. The primary goal of this article is to answer the question: "What values and characteristics do Qanats possess?".

This article also aims to provide a comprehensive and holistic overview of Qanat as multi-layered water system, offering a complete picture of these traditional infrastructure.

Since the most significant feature of Qanat is its functional role as a water infrastructure, this research has tried to deal with this phenomenon under the "infrastructure" literature. Therefore, the two main areas of "infrastructure" and "Qanat" have been presented as the background of the research.

Infrastructure

Urban infrastructure networks serve as vital lifelines for modern cities (Yang 2018). The scale and population of contemporary urban areas make life without essential infrastructures like water, energy, and transportation virtually impossible. These components are critical for distributing goods and services, enabling resource flow, powering businesses, and connecting communities. Essentially, infrastructure acts as the backbone sustaining the economic and social fabric of cities (Timilsina et al. 2020).

While the term "infrastructure" is modern, its history extends far back, encompassing the development of infrastructure in historical indigenous settlements such as Qanats and Stepwells.

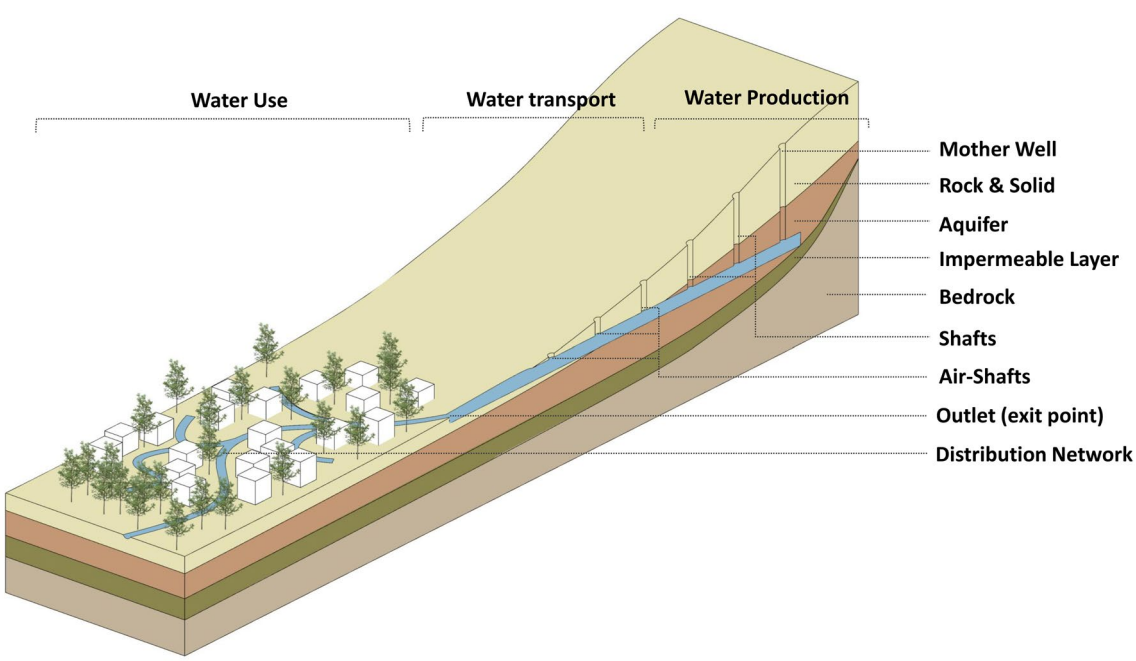

Fig. 1 Qanat Diagram (Source: Authors inspired by Estaji & Raith 2016)

In traditional contexts, knowledge production was rooted in the interconnectedness of the human, natural, and spiritual realms. This perspective resulted in indigenous knowledge being characterized as holistic due to its relational dynamics (Kinchelo and Semali, 2011).

For example, Indigenous societies, in their approach to water sources, prioritized holistic spiritual and natural connections, valuing nature's needs over human consumption. Water held a sacred role in their existence, viewed spiritually rather than economically, reflecting their profound beliefs and values (Groenfeldt 2003). Roman Roads are another examples of historical infrastructures, which serve a purpose beyond facilitating travel from one point to another. They encapsulate matters of ideology, authority, and self-definition, intertwined closely with the way we shape our perceptions of the world within societal contexts (Forcey et al 1998).

However, modernist science simplifies consciousness to physiological neuroprocesses, overlooking how dissecting the components of a whole weakens our understanding of social, physical, and human phenomena. Cartesian-Newtonian perspectives perceive "wholes" and their relationships as less genuine than distinct parts (Kinchelo and Semali, 2011). Therefore, since the modernization and post-Cartesian era, there has been a fundamental change in infrastructure, similar to other phenomena. During this period, the design of infrastructure was done separately and with a technocratic approach.

Infrastructure is usually divided into two general categories: hard and soft. Hard in infrastructure includes physical networks such as transportation (roads, mass transportation, rail ways, etc.), facilities (water, sewage, electricity, telephone, internet etc.), and other such networks, while soft infrastructure includes institutional systems such as, school, college, hospital, courts, municipality building, bank, post office, cinema, theatre hall, etc. These infrastructures meet the economic, social, and other needs of society (Rouse et al. 2013). From the

Table 1 different approaches towards infrastructure (source: Alhashemi et al., 2017 and Authors' significant revision)

Approach	Date	Proponent of an idea	Definition
Technocratic infrastructure		From the beginning of the modern period	Urban infrastructures such as road networks, waterways, railroads, sewage systems, electricity transmission lines, and the like have enabled the formation and development of the modern city. It is a Partial and technical approach
Green infrastructure	1994	Report on Conservation Strategies in Florida	The term was first coined in the Report on Conservation Strategies in Florida Equivalence of Natural Network (Green Infrastructure) and Civil Service Network (Gray Infrastructure) Values. (Firehock 2015)
	2002	Benedict and McMahon	Green infrastructure is an ecological connected network essential for environmental, social, and economic sustainability.(Benedict and McMahon 2002)
Ecologic infrastructure	2010	Ming Xu	The term was first coined by Ming Xu (Pandit et al. 2017)
	2014	Hillary Brown	An integrated ecological system where there are symbiotic and synergistic relationships among its main flows, providing a holistic perspective on urban infrastructures. In this approach, a complex and adaptable system emerges, with its sustainability arising from intricate interactions of engineering, environmental, and economic infrastructures tied to the city across time and space. (Pandit et al. 2017; Brown 2014)
Landscape infrastructure	1996	Garry Strang	The term was first coined by Garry Strang (Ji and Shao 2017)
	2009	Pierre Belanger	He determined this term. He presented a large-scale image of the landscape that can serve the city, guide the flow of resources and energy, and showcase dynamic and flexible changes in urban development. (Belanger 2009)
	2013	C.Rouse	It emphasizes the social values and the functional significance of systems and natural lands as much as the value of grey infrastructure. Another key concept is enhancing the aesthetic values of grey infrastructure. Moreover, landscape management is also interlinked with natural habitats to achieve specific human objectives. (Rouse et al. 2013)
	2015	Mansoury and Alhashemi	the natural infrastructure within a city that, through a landscape approach in both tangible (physical) and intangible (social and cultural) dimensions, becomes interconnected with urban structures. It simultaneously fulfills three functional, aesthetic, and identity-related objectives of the landscape. (Mansoury and Alhashemi 2015)

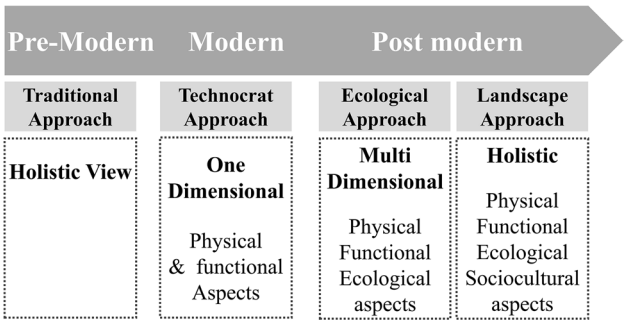

Fig. 2 infrastructure's transition (Authors)

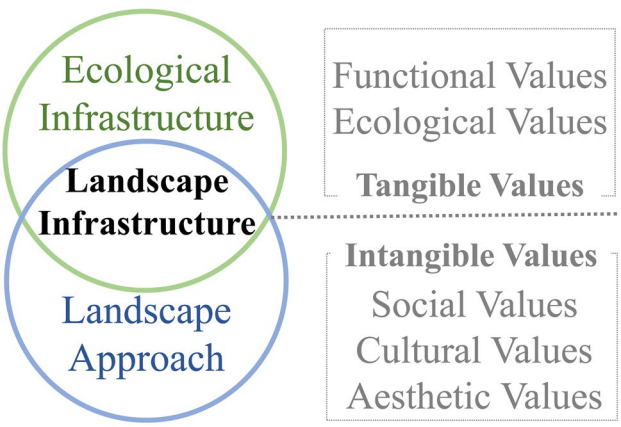

Fig. 3 Landscape Infrastructure Diagram (Authors)

postmodern era to the present day, this perception and division are common in the field of urban infrastructure.

In the second half of the twentieth century, various events revealed the limited capacity of industrial and technocratic infrastructure to meet the complex challenges of urbanization, such as falling bridges, canal failures, submerged beaches, power outages, water shortages, sewage decay, and so on (Belanger 2009; Rouse et al. 2013). For example, the toxic tragedy of Love Canal in 1987 (Belanger 2009), Francis Dam disaster in 1928 (Hundley et al 2016). Moreover, the advent of ecological branches, and the publication of the book "Design with Nature" by Ian McHarg in 1969, as well as his activities in television programs and academic spaces, a deeper understanding of the long-term effects of industrialization and urbanization on biophysical systems among the community and professionals emerged. This led to a renaissance in urban development approaches. Furthermore, the introduction of the term "green infrastructure" in architectural and urban literature by Benedict and McMahon in the early twenty-first century laid the foundation for modern approaches in urban infrastructure. It ushered in a new phase of the relationship between humans and the natural environment, shifting the focus from dominating nature to conserving it as a predominant approach (Wright 2011).

The ecological approach was subsequently introduced, which considers urban infrastructure systems as an integrated ecological system. In this approach, urban infrastructure is a complex and flexible system whose stability and resilience are associated with complex interactions and changes in the engineering, environmental, and economic infrastructure of a city over time and space (Pandit et al. 2017; Brown 2014). As different urban infrastructures have a multi-layered relationship with each other, designing and planning them separately can lead to an increase in costs and negative environmental consequences. Therefore, in the ecological infrastructure approach, the grey and green infrastructure systems, as well as socio-economic flows (considering the stimuli of decision-making and investment as well as the flow of wealth and welfare in society), are viewed in a unified manner in urban planning.

Another approach, landscape infrastructure, was introduced in response to environmental hazards and the limitations of technocratic infrastructures, as well as the influence of phenomenology in philosophy and cognition. In addition to the physical protection provided by ecological infrastructure, landscape infrastructure deals with the semantic and intrinsic values of a city's infrastructure.

In 2009, Pierre Belanger provided a comprehensive definition and overview of landscape infrastructure, which offered a large-scale perspective on the effects that it can have on a city, such as providing services, diverting resources and energy flows, and facilitating dynamic and flexible changes for a city's expansion, all of which are important for supporting and developing a city (Belanger 2009).

According to Belanger's definition, landscape infrastructure considers the environmental and social problems of the post-industrial era and their impact on lifestyles, business, and the economy together in an integrated framework called the city landscape (Rouse et al. 2013). Landscape infrastructure studies the possibility and method of combining landscape and grey infrastructure, which can lead to a holistic approach to infrastructure management (Ji and Shao 2016, 2017).

Mansouri and Aleashemi emphasize the importance of integrating nature with social, cultural, and identity issues in landscape infrastructure. They consider it a natural infrastructure within a city, which is linked to the landscape approach in physical and sociocultural aspects, and simultaneously serves functional, aesthetic, and landscape identity goals. Landscape infrastructure is not

Table 2 Different field of science which have studied Qanat. (Source: Authors)

Category	About	Sources
Hydrology and technical innovation	Technical (structure, digging, ect) and hydrological aspects of Qanat is considered in various researches and in all periods	Colonel and Noel 1944; Becket and Smith 1953; Beaumont 1971; Goes et al. 2017; Hamidian et al. 2015; Bailiff et al. 2015; Amin et al. 2009; Zarabi et al. 2017; Zolfagharian et al. 2019
	Innovative research has been conducted to increase the hydration of Qanat and develop techniques for tunnel repair	Sedghi and Zahn 2020, 2022; Jayhani and Asadi 2019; Habibzadeh et al. 2020
Built Environment	This category of articles investigates the impact of Qanats on the structure of cities and villages. It explores how both the physical and social aspects of urban areas are shaped by the presence of Qanats	Lightfoot,1996; Hosseini et al 2010; Laghaei et al 2012; Sheibani and Farahani Fard 2013; Najjar Najafi and Latifian Esfahani 2013; Rafiee Fanood 2014; Iranmanesh et al 2014; Estaji and Raith 2016; kalantari et al. 2017; Semsar Yazdi and Karimian 2018; Nikfarjam and Alalhesabi 2018; Soltanimohammadi and Yusefi 2019; Semsar Yazdi and Karimian 2021; Kowkabi 2021; Iranmanesh et al 2021; Talebi and Azad 2021; Nejad Ebrahimi 2021
Water Management and Social Science	Management of Qanats has always been tied to community participation and customary and social laws. Therefore, when considering Qanats from a water management perspective, we unconsciously must delve into their social aspects. To make Qanat water management feasible in traditional societies, a set of laws and social roles have been established. Numerous scientific studies have been conducted in this regard	Motiee et al.: 2006; Semsar Yazdi and Labbaf Khaneiki (2019); Jomehpour 2009; Fadakar Davarani 2009; Faraji Sabokbar 2012; Hosseini and Jahandideh 2016; Charbonnier 2018; Remmington 2018; Fadakar Davarani and Samaraam 2018; Labbaf Khaneiki 2022; Salemi Ghamsari 2019; Janebelahi 2022; Saif Al-Ghafri et al 2023
Environment & Sustainability	In recent years, Numerous articles have discussed Qanats from a sustainability standpoint. This category of studies presents a more comprehensive view of Qanats compared to other articles. They endeavor to examine Qanats simultaneously within the realms of environmental, economic, social, and cultural domains	Radaei et al. 2021; Nasiri and Mafakheri 2015; Jomehpoor 2006; Hosseini Fahraji and Sharifzadeh 2016; Vayysi 2021; Tabatabaei and khozeymehnezhad 2019; Ghods et al 2015; Sadeghizadehbafandeh et al 2019; Sharafi et al 2016; Radaei et al 2020; Bouzarjomehri and khatami 2018; Labbaf Khaneiki et al 2022
Geography	These studies delve into various aspects of Qanat geology, such as identifying sections of Qanats susceptible to settling or locating historical Qanat channels using modern geological methods and equipment	(Bagheban-Golpasand et al. 2019; Fattahi.M, 2015; Santos and Alfaro: 2014; Naghibi et al 2015; Naghibi et al 2018; Bailiff et al. 2018; Hojat et al 2016; Hajian et al 2009)
Biology & Aquatic	Given that Qanats serve as habitats for various aquatic species as well as plants, they have also been studied from this perspective	Mansouri et al 2010; Pourkhabbaz and Mohseni 2012; Sharafi et al 2013; Johari et al. 2009; Hashemzadeh Segherloo I, 2015; Azh et al 2015; Khalaji et al 2016; Ramin M, Doustdar 2019
Heritage and History	Many historians have explored the historical values of Qanats. In these studies, Qanats have been regarded as a valuable cultural heritage, symbolizing historical significance	Lightfoot 1996; Qassabiyan 2003; Parise 2016; Labbaf Khaneiki 2016; Sanaan Bensi 2020
Chemistry	This type of research focuses on assessing the water quality of various Qanats. These studies involve conducting experiments to determine whether the water from the case study is suitable for different purposes, such as irrigation, domestic use, drinking, etc	Kazemi et al.:2022; Rouhani 2021; Safari et al 2021; Nakhaei and Vadiati 2012
Rehabilitation	This category of research has examined the rehabilitation of indigenous technologies, collaborative conservation approaches, and the impact of public education on Qanat preservation	Ebizadeh 2011; Memon et al 2017; Zivdar and Kermanian 2020; Islami et al 2021; Karimian et al. 2021
Cultural Science	In this category of studies, the symbolic values of Qanats have been discussed, many of which trace their origins to the ancient reverence for water among Iranians. Furthermore, the role of Qanats in shaping the identity of Iranian communities and cities is discussed	Habibi et al 2016; Javadi and Arabsolghar 2013; Labbaf Khaneiki 2020; Papoli Yazdi and Vosoghi, 2019

Table 2 (continued)

Category	About	Sources
Archaeology	Historical Qanats, like any ancient structures, have been of interest to archaeologists. The perspective of these experts revolves around the historical value of Qanats, viewing them as historical artifacts	Shams: 2014; Charbonnier and Hopper 2018; Ramezanzadeh and behnamfar 2018; Mashhadi 2021
Disaster Risk	Given that many Qanats have dried up today, the possibility of their subsidence exists. Experts in this field address Qanats as an issue that could potentially lead to a crisis	Parsizadeh et al 2015; Abbasnejad 2016; Rahimi 2017
Tourism	These articles explore the intersection of Qanats and tourism. Qanats, both as historical artifacts and sources of water supply, can play a significant role in the tourism sector	Abadian 2017; Labbaf Khaneiki et al 2023
Philosophy	This represents a novel category that explores Qanats. Asgharzadeh introduces a distinctive and somewhat unconventional concept, suggesting that Qanats can be seen as a form of semi-smart technology. He provides a series of facts and examples to substantiate this notion	Asgharzadeh 2017

only a service but also intertwined with urban life and citizens in various aspects. The stability and durability of this infrastructure in the city and its structures are crucial factors in the quality of urban landscapes. They also present the landscape approach as a multidimensional, objective- subjective, and holistic solution to address the rigid and one-dimensional nature of infrastructure that emerged during the industrial era, and to enable the multifaceted presence of infrastructure in the city as a whole (Alehashemi et al 2017; Alehashemi et al. 2015). (See Table 1).

As mentioned, approaches in infrastructure have evolved from the beginning of the modern era to the present, aiming to address infrastructure-related issues and enhance the quality of life. These developments have ranged from a technocratic approach to green infrastructure, ecological infrastructure, and landscape infrastructure. This progression, in parallel with the development of the concept of sustainability, has moved away from purely physical and functional perspectives and has also encompassed other environmental, social, cultural, and economic aspects.

The most recent approach) landscape infrastructure(, Because of its objective and subjective dimensions, has a greater potential to address the complex and multifaceted problems of contemporary urban infrastructure (See Figs. 2, 3).

Qanat

Qanat, an ingenious water management system, holds deep historical and cultural significance as an ancient method of supplying water in arid regions, contributing to sustainable agriculture and settlements. For a thousand years until today, this phenomenon has been the subject of research and study by scientists.

Al-Karji's book is likely the oldest text about Qanat (Iranmanesh et al. 2021).

In around 1010 AD, Al-Karaji compiled the achievements and personal experiences, along with the insights of his predecessors, on the digging of Qanats, in his book "Extraction of Hidden Waters." Despite its scientific content, this treatise was not widely utilized and was forgotten in its time. In fact, those who could benefit from it (the diggers of Qanats) were rarely able to read. However, this book holds significance for documenting an ancient engineering method and preserving traditional knowledge (Goblot 1979).

Later on, in the 1930s, Goblot, a French scientist was invited by the Iran government to conduct research about Qanat. And he published the result of his research in a book titled "Qanat a technical for Accessing Water,". In the book he attributed the invention of Qanat to the miners and introduced the technical and cultural features of Qanat. He also proposed the theory that Qanat was originally invented to drain mine tunnels and later was used as a water extraction system (Papoli Yazdi and Vosoghi 2019).

This book holds significance in emphasizing the importance and technical, historical values of Qanats, demonstrating that Qanats are not merely an insignificant traditional water system; rather, they are a valuable and noteworthy phenomenon, capable of being a subject of research for scholars. Since then, various scientific articles have discussed different aspects of Qanat.

In the result section, a detailed discussion will be provided regarding the perspectives on Qanats in various historical periods. Here, to enhance the organization of the text, we will delve into mentioning the different branches through which Qanats have been examined. Hydrology and technical innovation, Built Environment, Water Management and Social Science, Environment & Sustainability, Geography, Biology & Aquatic, Heritage & History, Chemistry, Rehabilitation, Archaeology, Disaster Risk, Tourism, Philosophy (See Table2).

Semsar Yazdi and Papoli Yazdi as well as Labbaf Khaneiki, have been among the researchers who have shown the most interest in Qanat, studying its technical, cultural, social, and economic aspects in various articles and books (Semsar Yazdi and Karimian 2018; Semsar Yazdi and Labbaf Khaneiki 2017; Semsar Yazdi and Karimian 2021; Papoli Yazdi and Vosoughi 2019; Labbaf Khaneiki 2015, 2017, 2020, 2022, 2023; Labbaf Khaniki et al. 2019, 2023).

Labbaf Khaneiki's research have focused on Qanat and he has published 48 research over last 18 years. Some of his research presented innovative perspectives on the Qanat phenomenon. For instance, he analyzed the position and function of endowments (Waqf) in the Karizi civilization in a chapter of the book "Hydro Social Cohesion in Iranian communities". There is a common belief that endowments have their roots in religious beliefs. In addition, regarding the endowment of Qanats, Labaf Khaniki presents the idea that endowments did not solely occur for the satisfaction of God; rather, they were a social mechanism to address and mitigate class disparities. Utilized the method of investigating historical texts and employing logical reasoning to substantiate his theory (Labbaf Khaneiki 2022). Moreover, he studied oral culture and customs related to Qanat in the book "Production and Water Culture" (Labbaf Khaneiki 2020) he and Semsar Yazdi also presented the same concept it the "interview with local participatory" book chapter. (SemsarYazdi and Khaneiki, 2023) These investigations are based on a reviewing historical texts, semi-systematic interview and content analysis.

Table 3 The Number of Papers with "Qanat" in the title and in Abstract; based on different publisher and fields. (authors)

Source	Science direct	Taylor and Francis	Springer	Magiran	Total
Title	14	8	30	72	124
Abstract	38	21	614	409	1082
Total	52	29	644	483	1205

Furthermore, PapoliYazdi perspective delves into the wider aspects of Qanat equipment and professions. He explores a network of traditional vocations related to the establishment of Qanats, delving into the examination of the Qanat's role in the economic life of communities. Moreover, his works aim to document historical tools by reviewing historical text and observation.

In conclusion, although Qanat has been studied in various fields, there is a vacant space for a comprehensive portrayal of it. While recent articles studying Qanats in the realm of sustainability have approached this comprehensive view, a review article is still necessary to summarize previous studies and present various aspects of Qanats side by side within one article.

Methods

Since the main objective of this paper is to provide a comprehensive perspective on Qanat, the "semi-systematic review" approach was chosen to conduct this research. The semi-systematic or narrative review approach is suitable for topics that have been studied in various disciplines (Wong et al. 2013). Additionally, this research method is suitable for depicting the progress of a subject over time or among different scientific traditions. In general, this type of review research aims to identify all research traditions related to the subject (Snyder 2019). Furthermore, researchers typically use over-arching narratives to synthesize different narratives to provide a general understanding of complex and extensive fields and issues. (Wong et al. 2013).

Therefore, given that Qanats have been studied across various disciplines and the aim of this article is to summarize all aspects of Qanats studied in these articles, the semi-systematic review method is an appropriate approach for this research.

In the upcoming research, the Landscape approach will serve as an over-arching narrative to comprehensively classify all the features of the Qanat. Because landscape approaches highlight the importance of inter- and trans-disciplinary collaboration. This means addressing interconnected challenges by fostering increased involvement across various scientific fields and engaging a wider range of stakeholders from society. So, this approach is able to bridge the gaps between research, policy, and practical implementation.

In the second step we should select a suitable type of analysis. Several methods can be employed to analyze and synthesize findings in a semi-systematic review. A common approach is thematic or content analysis, which involves identifying and presenting patterns in the form of themes within the text. (Braun and Clarke 2006). Since our research is a review article and the material of our study consists of textual content, thematic analysis has been chosen as a suitable method for this research.

In the first step, we searched the Magiran website for Persian papers. For English sources, we searched through Science Direct, Taylor and Francis, and Springer. The MagIran database was chosen for its capability to index almost all reputable Persian scientific articles and journals. The selection of 'Springer,' 'ScienceDirect,' and 'Taylor & Francis' databases was guided by their strong academic reputation, extensive coverage across disciplines, and robust search capabilities. 'Springer' offers a broad range of impactful research, while 'ScienceDirect' provides a diverse array of cross-disciplinary content. 'Taylor & Francis' boasts comprehensive coverage across academic fields. These choices were made to ensure access to high-quality, peer-reviewed articles and enhance the credibility and depth of our study. (See Table 3).

Initially, we conducted a search using the keyword "Qanat" specifically within paper titles, ensuring that the articles under consideration were directly focused on the topic of Qanats. During this phase, 74 Persian articles and 49 English books and articles from various disciplines, including "Hydrology and Technical Innovation," "Built Environment," "Water Management and Social Sciences," "Environment and Sustainability," "Geography," "Biology and Aquatics," "Heritage and History," "Rehabilitation," "Chemistry," "Cultural Science," "Archaeology," "Disaster Risk," "Tourism," and "Philosophy," were found.

Then all 123 founded articles (all have Qanat key word in their title) were carefully studied. Then, using the Thematic Analysis method, all the passages were analyzed to find the various values and features of Qanat. Thematic Analysis is a common method to identify, analyze, and report patterns in the form of themes of a text (Braun and Clarke 2006). The statements in the text of the articles were analyzed to identify tangible and intangible values of Qanat as desirable themes based on logical reasoning. Every part of the text that refers to a feature of the Qanat forms the statement, and the referred feature, which is a summary of the statement, forms the theme. For example," Qanat, Traditional Eco-Technology for Irrigation and Water Management" (statement) refers to

Table 4 The Number of papers with Qanat in their title and abstract in four data bases

Field	Data Base	Num (Qanat in title)	Num (Qanat in abstract-selected papers)	Total	Per %
Hydrology-Technical Innovation	Science Direct	7	1	42	29.577
	Taylor & Francis	4	0		
	Springer	11	0		
	Magiran	18	1		
	Total	40	2		
Built Environment	Science Direct	1	1	18	12.676
	Taylor & Francis	1	1		
	Springer	2	0		
	Magiran	9	3		
	Total	13	5		
Water management & Social Science	Science Direc	0	2	16	11.268
	Taylor & Francis	2	0		
	Springer	3	0		
	Magiran	8	1		
	Total	13	3		
Environment and Sustainability	science direct	1	0	13	9.1549
	Taylor & Francis	0	0		
	Springer	3	0		
	Magiran	8	1		
	Total	12	1		
Geography	science direct	3	2	12	8.4507
	Taylor & Francis	0	0		
	Springer	4	0		
	Magiran	3	0		
	Total	10	2		
Biology & Aquatic	science direct	0	0	10	7.0423
	Taylor & Francis	1	0		
	Springer	0	0		
	Magiran	9	0		
	Total	10	0		
Heritage-History	science direct	0	1	7	4.9296
	Taylor & Francis	0	0		
	Springer	2	0		
	Magiran	4	0		
	Total	6	1		
Rehabilitation	science direct	0	0	5	3.5211
	Taylor & Francis	0	0		
	Springer	2	1		
	Magiran	2	0		
	Total	4	1		
Chemistry	science direct	1	0	5	3.5211
	Taylor & Francis	0	0		
	Springer	1	0		
	Magiran	3	0		
	Total	5	0		

Table 4 (continued)

Field	Data Base	Num (Qanat in title)	Num (Qanat in abstract-selected papers)	Total	Per %
Cultural Science	science direct	0	0	4	2.8169
	Taylor & Francis	0	0		
	Springer	0	1		
	Magiran	3	0		
	Total	3	1		
Archaeology	science direct	0	1	4	2.8169
	Taylor & Francis	0	0		
	Springer	1	0		
	Magiran	2	0		
	total	3	1		
Disaster Risk	science direct	1	0	3	2.1127
	Taylor & Francis	0	0		
	Springer	1	0		
	Magiran	1	0		
	Total	3	0		
Tourism	science direct	0	0	2	1.4085
	Taylor & Francis	0	0		
	Springer	0	0		
	Magiran	1	1		
	Total	1	1		
Philosophy	science direct	0	0	1	0.7042
	Taylor & Francis	0	0		
	Springer	0	0		
	Magiran	1	0		
	total	1	0		
total	science direct	14	8	**142**	**100**
	Taylor & Francis	8	1		
	Springer	30	2		
	Magiran	72	7		
	Total	**124**	**18**		

"ecological" feature of Qanat (theme). We identified 20 features based on 356 statements.

At this stage, the mentioned statements and themes were categorized into sustainable discipline fundamental categories: "environmental," "economic," and "socio-cultural," to organize the research process. Since the concept of sustainability is the dominant paradigm in various filed and sections in today's world, it was chosen as the basic factor for categorizing the result (Castro 2004).

Next, all statements were summarized, and themes that represented content close to each other were combined. Some topics were divided into several different topics according to the scope of the subject. At the end of this stage, five themes were identified in the environmental category, three in the economic category, and thirteen in the socio-cultural category.

In the third step, 1082 papers were identified by searching for "Qanat" among abstracts and keywords in the four mentioned databases. After scanning abstracts, papers that presented a unique perspective on Qanat were selected for reading the entire texts. And then 17 papers were selected and then analysed exactly the same as papers in previous step. Subsequently the table of themes and statements was completed. In the final step, the various features of the Qanat were classified into a comprehensive framework based on the landscape approach. (See Table. 4 and Figure 4).

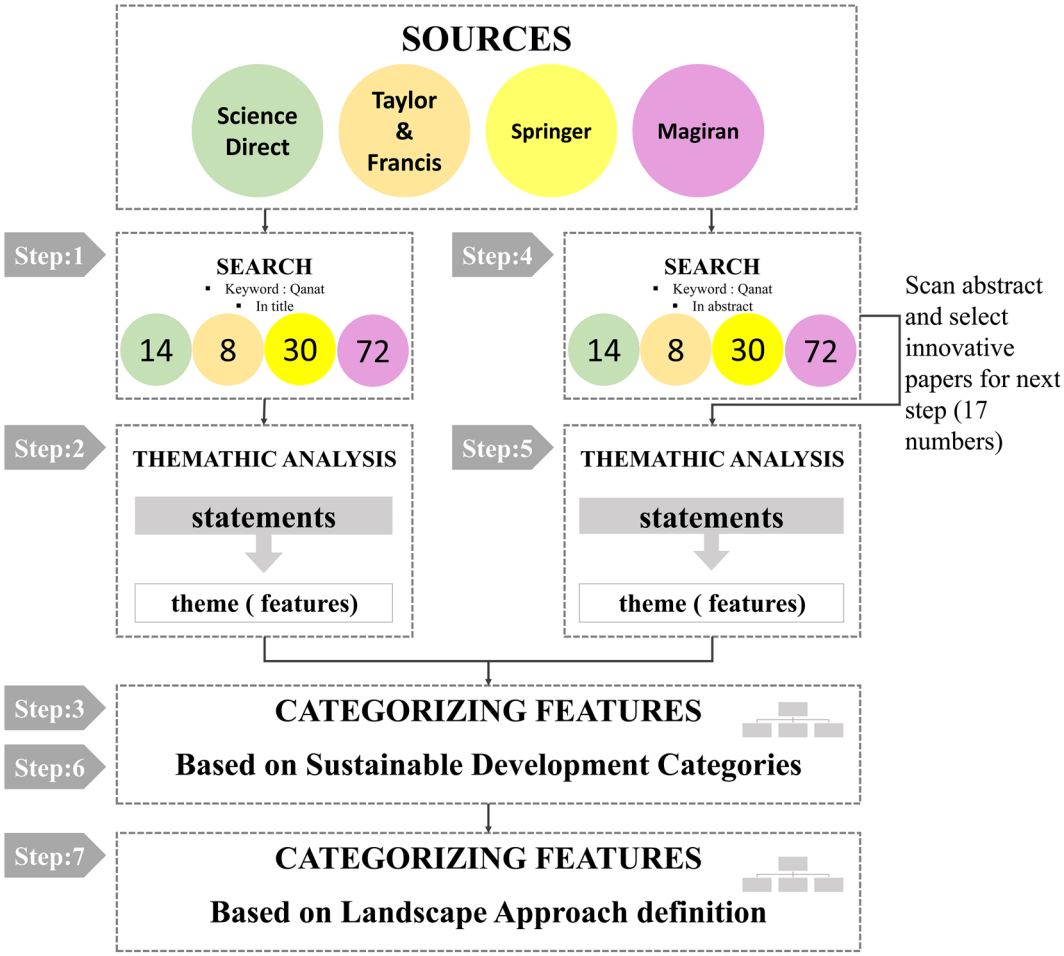

Fig. 4 flowchart of research steps (source: authors)

Results

Statistical analysis of results

Since the Qanat is a complex invention with diverse territorial and ethnic characteristics, and has spread to different countries and territories, it has been studied in various disciplines. However, the technical aspects of the Qanat as a water infrastructure have been studied more than other features. with a 32% share of studies and a total of 40 studies. These studies include a technical-analytical examination of Qanat in different regions, as well as technical innovations and suggestions for modernizing the Qanat.

After that Built Environment is the discipline with the highest number of papers related to the Qanat, accounting for 11% and a total of 13 studies.

Since 2003, specialists from more fields have shown an increased interest in Qanats.

Water management and social Science, Environment and sustainability, geography, biology, heritage- history, chemistry, rehabilitation, cultural science have paid the most attention to the Qanat, with 11% (13 number), 10% (12 number), 8% (10 number), 8% (10 number), 5% (6 number), 4% (5 number), 3% (4 number) and 2% (3 number), respectively.

During last ten years, scholars from four new fields have studied Qanat. Archaeology, disaster risk, tourism, and philosophy with 2% (3 number), 2% (3 number), 1% (1 number), 1% (1 number), respectively. (See Fig. 5).

Generally, as science has developed in various fields, research related to the Qanat has also experienced an upward trend. A glance at (Fig. 6) shows that the Qanat has been prominent in the academic sector as an infrastructure with outstanding technical features in different periods.

However, with the development of other trends, such as sustainable development and ecological, economic, and sociocultural values, the unique cooperative management of Qanat's water infrastructure has been gradually taken into consideration. In recent years, architects, urban planners, and landscape architects have paid more

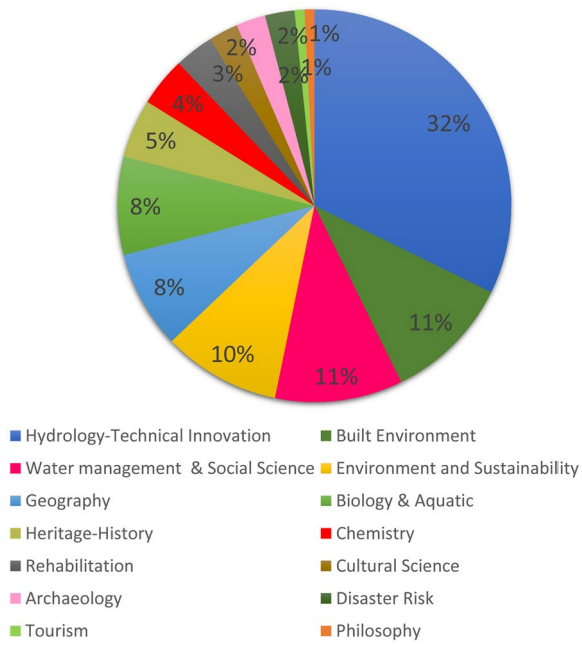

Fig. 5 The percentage of published articles on "Qanats" (with the keyword "Qanat" in the title) in various fields

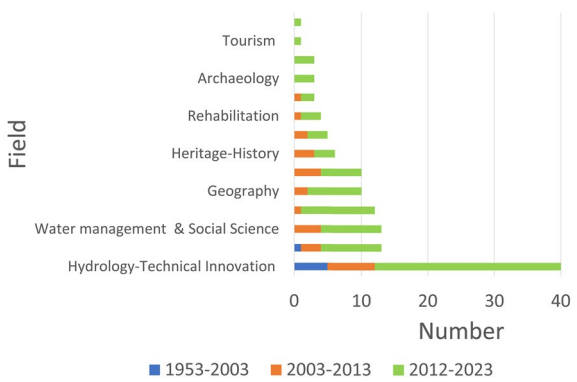

Fig. 6 The percentage of published articles on "Qanats" (with the keyword "Qanat" in the title) in various fields

attention to the role of Qanat in the formation of urban and rural structures than in previous years. Based on presented charts, disciplines such as sustainability, sustainable architecture and urban planning, and landscape architecture (in the field of build environment) have attempted to study Qanat with a holistic view. However, the multiplicity of features of the Qanat has caused researchers to only mention its values in headlines or fail to address them fully. In the last ten years, researchers in the fields of geography, biology, reconstruction, archaeology, disaster risk, history, cultural heritage, philosophy, and tourism respectively have published the most articles about the Qanat. This indicates that the features of the Qanat have been studied with a deep, specialized, and practical view in different fields, and it seems that this trend will continue in the coming years.

The features of the Qanat

The statements referring to the characteristics of the Qanat were extracted from the texts of articles in different fields in order to identify the features of the Qanat. This research has identified all the features of the Qanat that have been mentioned directly or indirectly in previous articles and summarized them into three groups: sociocultural, economic, and environmental. (See Fig. 7).

The following tables present the definition of each feature (See Tables 5, 6, and 7).

Discussion

As indicated by the section of statistical findings, Qanat have been extensively studied in various scientific fields, ranging from hydrology to cultural and social aspects, due to their multifaceted values. It seems that one of the most important aims of all these research endeavors is to preserve this phenomenon.

However, having a comprehensive understanding of multi-layered heritages is crucial for their revitalization and restoration with a holistic and all-encompassing approach (Mısırlısoy and Günçe, 2016). One-dimensional perspectives in Qanat planning and management have stripped them of their intangible significance, leading to their gradual decline or alteration over time.

The revival and protection of the Kish Qanat system is a prime example of this one-dimensional perspective on Qanats. In this project, the structure of the Qanat was initially restored, and some of the dry branches of the Qanat were allocated for uses such as cafes, restaurants, and exhibitions, actually its new function is museum (Alemohammad and Gharari 2017). In this project, only the physical structure of the Qanat has been preserved, while other social, cultural, and economic values associated with it have been neglected. Today, the Qanats in the city of Kish bear little resemblance to the life and essence of Qanats in the past. (See Fig. 8).

Returning to the main point, the functional performance of Qanats as a water supply system has consistently been their most emphasized value across all disciplines, making it appropriate to classify Qanat values within the context of infrastructure definition.

Another reason for exploring Qanat in the literature on water infrastructure is that they are typically evaluated within this domain, and decisions are made concerning them. For example; In Iran, the management and oversight of Qanats are under the jurisdiction of the Ministry of Energy and the Ministry of Agriculture, Jihad, and Natural Resources. These two ministries have

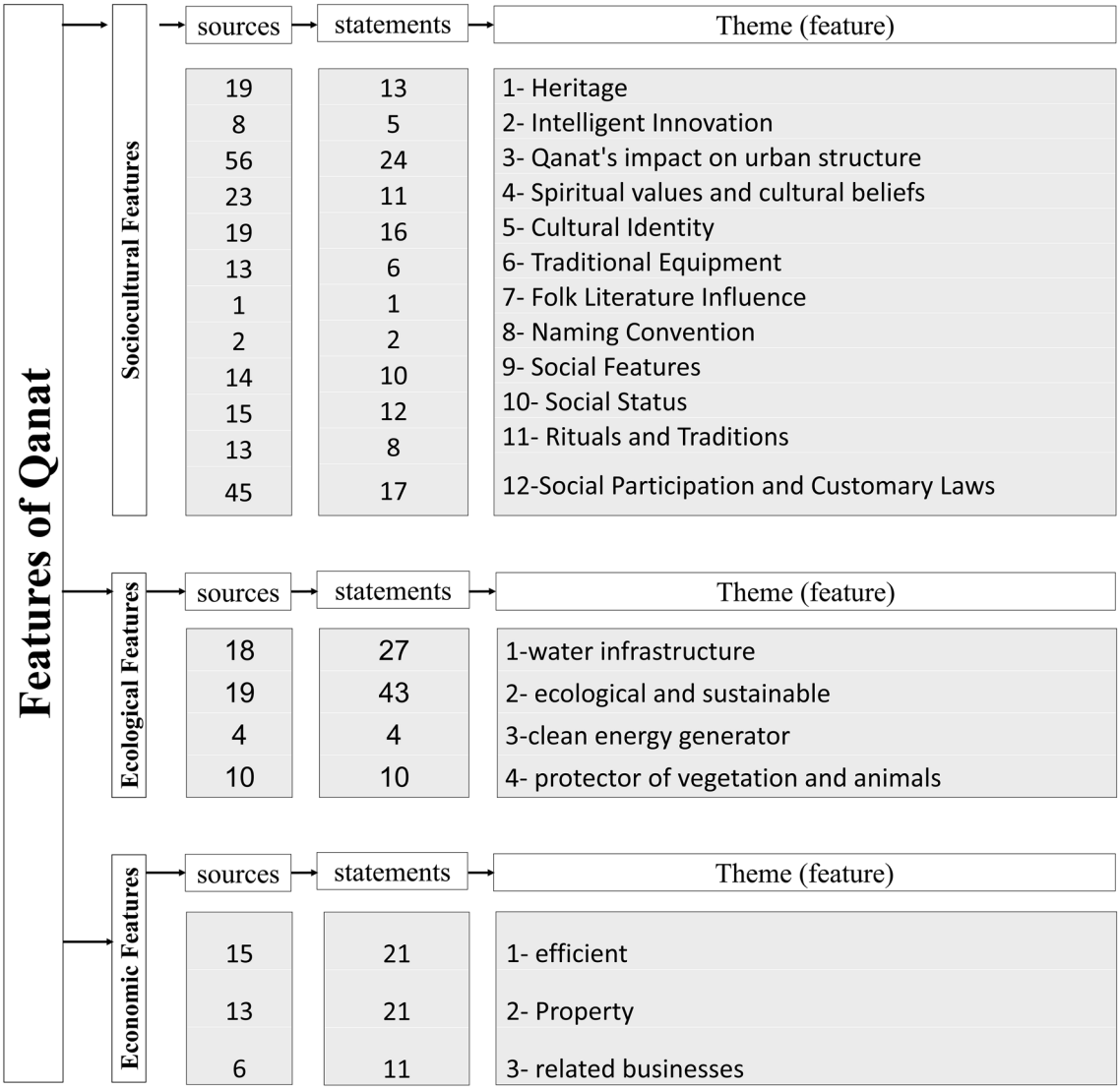

Fig. 7 the number of statements and sources supported ant theme (features)

various responsibilities, including the supervision of water resources, irrigation infrastructure, and water distribution, and in Oman the Ministry of Regional Municipalities and Water Resources is officially responsible for Qanats.

In practice, Qanat systems are often viewed solely as water infrastructure and are compared unfavorably to other modern water supply systems, deeming them as outdated and inefficient. While scientific and managerial prudence prevents a demolition verdict, the lack of attention to this phenomenon and the absence of a well-defined preservation plan indirectly leads to their elimination. (Hosseini et al 2010; Abbasnejad 2016, Ahmadi et al 2010; Lightfoot 1996).

While considering the functional, cultural, social, and heritage values of Qanat is crucial, presenting a comprehensive image of Qanat as a multi-layered value-laden water infrastructure requires practical and applied research.

Each Qanat has unique technical specifications, including factors like water yield, well and water channel durability, groundwater volume, and more. These complexities require thorough technical examination and precise testing. For example, in-depth technical studies employ various fields and methodologies, such as Tectonic geomorphology (Taib et al. 2023), to address these specificities.

Table 5 Cultural and Social Features (source:authors)

Theme	1- Heritage
Explanation	Qanat is a historical heritage invented by Iranians 2500 years ago. It was also added to the UNESCO World Heritage List in 2016
Sources	Naghedifar et al. 2020; Motiee et al. 2006; Sanaan Bensi 2020; Ebizadeh 2011; Hamidian et al. 2015; Parsizadeh et al. 2015; Kowkabi 2021; Bagheban-Golpasan et al. 2019; Motiee et al. 2006; Hosseini et al. 2010; Shams 2014; Sedghi and Jan 2020; Motiee et al. 2006; Jomehpour 2009; Naghedifar et al. 2020
Theme	2- Intelligent Innovation
Explanation	The Qanat is an intelligent innovation that represents the genius knowledge of water engineering in Iran. The Qanat is considered a wonder due to the precise leveling techniques of ancient Iranian engineers with primary tools and accurate mathematical calculations
Sources	Hamidian et al. 2015; Motiee et al. 2006; Kowkabi 2021; Hamidian et al. 2015; Stiros. 2006; Motiee et al. 2006; Ebizadeh 2011
Theme	3- Qanat's impact on urban structure
Explanation	In cities supplied by the Qanat, the water supply network has influenced the location and development patterns, as well as the physical structure and spatial order of neighborhoods, collective spaces, houses, public buildings, agricultural lands, gardens, green corridors, and green spaces Landmark buildings such as mosques, schools, aristocratic houses, and caravanserais were built along the main route of the Qanat. The construction and placement of water facilities such as wells, houses, brooks, ponds, reservoirs, Qanat, refrigerators, bathrooms, fountains, dams, and pools have also been influenced by the Qanat. Furthermore, the urban road network was formed based on the hierarchy of the water distribution network, with routes usually following the path of the underground channels and streams, and surface channels of the Qanat. The social hierarchy and land prices in urban and rural areas were also determined by their location in relation to the Qanat. The higher social classes lived upstream, while the lower classes lived downstream. Housing and land prices were usually higher in areas with access to Qanat water
Sources	Sanaan Bensi 2020; Estaji and Riath 2016; Radaei et al. 2021; Santos and Alfaro 2014; Nikfarjam and Alalhesabi 2018; Asgharzadeh et al. 2017; Kalantari et al. 2017; Soltanimohammadi and Yusefi 2019; Habibi et al. 2016; Faraji Sabokbar 2012; Janebelahi 2019; Jomehpour 2006; Vayysi 2021; Radaei et al. 2020, 2021; Jomehpour 2009; Zivdar and Karimian 2020; Santos and Alfaro 2014; Rafiee Fanood 2014; Radaei et al. 2020; Janebelahi 2019; Soltanimohammadi et al. 2018; Papoli Yazdi and Vosoghi 2019; Kalantari et al. 2017; Jayhani and Asadi 2019; Janebelahi 2019; Labbaf Khaneiki 2019; Santos and Alfaro 2014; Estaji and Riath 2016; Iranmanesh et al. 2021; Janebelahi 2019; Jomehpour 2009, 2006; Sheibani and Farahanifard 2013
Theme	4- Spiritual values and cultural beliefs
Explanation	Spiritual values and cultural beliefs are deeply intertwined with the Qanat, with ancient Iranian traditions, Zoroastrian religion, and Islam all contributing to its significance. The dry climate and scarcity of water resources in the region have intensified the reverence for water, which has had a profound impact on the practices and customs of using and maintaining water. Following the advent of Islam, the attribution of water-related elements, such as drinking fountains, to religious leaders has further reinforced social responsibility for water usage and maintenance methods. Additionally, the tradition of endowment, which is rooted in religious beliefs, has led to the development of public water facilities, such as Qanat, water mills, and reservoirs, while also promoting economic balance
Sources	Kowkabi 2021; Radaei et al. 2021; Labbaf Khaneiki 2022; Soltanimohammadi et al. 2018; Sharafi et al. 2016; Jomehpour 2009; Soltanimohammadi and Yousefi. 2019; Tabatabaei and Khozeymehnezhad 2019
Theme	5- Cultural Identity
Explanation	The Qanat is a symbol of Iran's cultural identity, reflecting its historical thinking, culture, and lifestyle. The Karizi (another name of Qanat) culture has distinct political, social, cultural, and economic characteristics. Sociologists assert that the people of the Karizi civilization are hardworking, thrifty, honest, trustworthy, and peaceful. Furthermore, they seek to achieve their goals through dialogue and negotiation. The traditions and norms associated with the construction and operation of the Qanat, which require extensive social participation, have helped shape these civilizational and cultural characteristics, passing them down from generation to generation
Sources	Kowkabi 2021; Hosseini et al. 2010; Semsar Yazdi and Karimian 2021; Labbaf Khaneiki 2020; Radaei et al. 2021; Papoli Yazdi and Vosoghi 2019; Habibi et al. 2016; Ebizadeh 2011; Tabatabaei and Khozeymehnezhad 2019
Theme	6- Traditional equipment
Explanation	Various tools and equipment related to the construction, maintenance, and management of Qanat reflect unique socio-cultural values. For instance, there are different types of water clocks with different names that vary from place to place. Bowls, tankers, well caps, ponds, and fountains are other examples. Papoli Yazdi has a unique perspective on Qanat construction tools, especially the well wheel, as he believes that it demonstrates the high level of technical and engineering ability of Iranians in various professions such as carpentry, masonry, metalwork, etc
Sources	Charbonnier 2018; Labbaf Khaneiki 2020; Soltanimohammadi et al. 2018; Abadian et al. 2017; Papoli Yazdi and Vosoghi 2019
Theme	7- Folk Literature Influence
Explanation	Since Qanat had a profound connection with Iranian everyday life, their influence can be found in the colloquial literature of the people. For example, Papoli Yazdi mentioned the proverb "I will not go to the well with your rope". Although the number of proverbs related to Qanat is not limited to this case, they are not frequently mentioned in published articles, and there is a research gap in exploring the influence of Qanat in official and colloquial literature
Sources	(Papoli Yazdi and Vosoghi 2019)
Theme	8- Naming Convention
Explanation	Many villages, streets, and neighborhoods were named after Qanat, such as Kahrizak and Karizabad. Additionally, some family names indicate that families were skilled in fields related to the construction of Qanat, such as Sangtrash (masonry) and Najjarzadeh (carpentry), which were used to make Qanat tools
Sources	Jomehpour 2009; Papoli Yazdi and Vosoghi 2019

Table 5 (continued)

Theme	9- Social Features
Explanation	Throughout history, Qanat has played an essential role in people's social lives as social-ecological systems. They have contributed to communities through watershed management, cooperative management systems for water distribution and maintenance of water facilities, rituals and ceremonies, endowment culture, land tenure patterns, and water ownership rights. Cooperation, convergence, and assistance were necessary for Qanat survival, which strengthened the social systems that depended on the Qanat. Therefore, the Qanat was a source of social capital in cities and villages. This social capital played a crucial role in people's resilience against environmental changes, political developments, and socioeconomic transitions
Sources	Kowkabi 2021; Labbaf Khaneiki 2019, 2022; Lightfoot 1996; Jomehpour 2009; Fadakar Davarani 2009; Tabatabaei and Khozeymehnezhad 2019; Radaei et al. 2021; Ebizadeh 2011
Theme	10- Social Status
Explanation	Since the Qanat plays a vital role in societies, people who preserve it due to their job, skill, or social role are respected. It should be noted that the economic value of water in the lands. Dependent on the Qanat means that the share and ownership of the Qanat's water affects people's social status. In these areas, the value and credibility of people depend on the amount of water ownership, and social status is defined accordingly. For example, Moghnais, who are responsible for consulting Qanat, have been respected by the general public and have a high social status due to the necessity of their job. Moreover, it is considered a highly respected job due to its difficulty and danger, as well as its high income. In areas related to this water system, Moghany is a trustworthy person and enjoys social respect. Sartaq, who has some responsibility in water distribution network, is also a respected person, and in some regions, the role of Sartaq is inherited from father to son It should be noted that the imbalance of water ownership can create social gaps. Therefore, wealthy people, often donate part of their water share to the public (to construct Qanat and various water structures) to maintain social balance and prevent social tensions. Also, the social status of people is reflected in the location of their housing relative to the Qanat and their access to clean water. The rich typically live in the upper reaches of the Qanat, while the poor live in the lower reaches of the Qanat
Sources	Parsizadeh et al. 2015; Lightfoot 1996; Stiros 2006; Jomehpour 2009, 2006; Labbaf Khaneiki 2022, 2020; Jomehpour 2009, 2006
Theme	11- Rituals and Traditions
Explanation	Many customs and rituals related to the Qanat can be observed in different regions of Iran. Many of them are inspired by ancient water sanctity rituals. For example, ceremonies such as Rain Gathering, Qanat Weddings, Choli Chaqal, and Sheep Sacrifice are held to increase the Qanat's water flow. The Qanat also plays a significant role in collective memories because many social events, such as the Moharram morning ceremony, take place near the Mazhar (Outlet) or the ponds in the centre of neighborhouds. It is worth noting that the endowment tradition, which is emphasized in both Zoroastrianism and Islam, has a socio-technical role in the construction and maintenance of the Qanat and other related hydraulic structures
Sources	Jomehpour 2009; Labbaf Khaneiki 2020; Bouzarjomehri and Khatami 2018; Hosseini et al. 2016; Abadian et al. 2017; Javadi and Arabsolghar 2013; Soltanimohammadi and Yousefi 2019; Sharafi et al. 2016
Theme	12- Social Participation and Customary Laws
Explanation	The social participation and customary laws related to the Qanat are reflected in the cooperative water management system of the Qanat. Due to the limited availability of Qanat resources, the existence of a social system that determines the roles (such as Mirab or Sartaq) and responsibilities of individuals in the Qanat irrigation network is necessary. This social system, which is based on cooperative management with a set of customary rules, achieves several goals, including preserving common water resources, maintaining privacy of water sources and water supply facilities, distributing water among stakeholders, managing water and the water market, and resolving disputes. This social system, which is often hierarchical, is not limited to the irrigation sector and extends to other social areas. Since social disputes can disrupt the irrigation cycle, people often resolve conflicts through compromise and dialogue. In this way, the physical structure and type of Qanat management leads to social cooperation and convergence. The irrigation cycle also necessitates a high level of cooperation, which helps all water stakeholders adapt to fluctuations in water flow
Sources	Labbaf khaneiki 2020, 2019; Jomehpour 2009; Radaei et al. 2021; Memon et al. 2017; Charbonnier 2018; Nasiri and Mafakheri 2015; Ahmadi et al. 2009; Charbonnier 2018; Tabatabaei and Khozeymehnezhad 2019; Papoli Yazdi and Vosoghi 2019; Fadakar Davarani 2009; Janebelahi 2019; Ghods et al. 2015; Sharafi et al. 2016; Bouzarjomehri and khatami 2018; Asgharzadeh et al. 2017; Sadeghizadehbafandeh, et al. 2019

Furthermore, numerous scientific chemical methods are available for assessing groundwater quality. One such method is Principal Components Analysis, which can be used to enhance our understanding of groundwater hydrochemistry (Kallel et al. 2018).

Moreover, while values, traditions, construction methods, and Qanat management techniques may share some similarities, they each possess distinctive characteristics in their specifics. For instance, by conducting in-depth semi-structured interviews with local community members (Brinkmann 2014), one can uncover the cultural and social values associated with a Qanat. Additionally, by analyzing the content of oral history and local customs (Krippendorff 2018), it is possible to identify the intangible values of a Qanat.

Besides, Qanat's footprint on the various city's structure can be traced by analyzing historical maps and the evolution of urban development.

Given the significance of Qanat in executive systems and the responsible entities for Qanat, the authors of this article believe that Qanat revitalization can only be

Table 6 Ecological features (source: authors)

Theme	1- Water Infrastructure
Explanation	The most important functional feature of the Qanat is its role as a traditional water supply system. For centuries, Qanat has been a reliable source of water in hot and dry climates, especially on the plateau of Iran, where it has made the region habitable and cultivated. Today, it is used in many regions around the world, including the plateau of Iran, for the agricultural sector. In addition to providing water for irrigation and drinking, Qanat have been integrated into the cultural infrastructure of cities and villages by supplying water for mosques, schools, baths, and funerals
Sources	Delfani et al. 2021; Kowkabi 2021; Sedghi and Zhan 2022; Bagheban-Golpasand et al. 2019a, b; Bailiff et al. 2015; Parsizadeh et al. 2015; Shams 2014; Hamidian et al. 2015; Lightfoot 1996; Colonel and Noel 1944; Motiee et al. 2006; Endreny 2008; Hosseini et al. 2010; Jomehpour 2009; Beaumont 1971; Charbonnier 2018; Vayysi 2021; Radaei et al. 2021
Theme	2- Ecological and sustainable
Explanation	Qanat is often referred to as a sustainable and environmentally friendly system in numerous articles. It uses only gravity for water extraction, does not create any pollution, and all the materials used in Qanat installations are environmentally friendly and recyclable Qanat transfer fresh water from the mountain to the downstream plains that have more saline soil, thus preventing the spread of desertification by keeping the soil moisture balanced, preventing soil salinity, and stabilizing the soil. As a water supply network, Qanat preserves and connects ecological elements and scattered biomes The Qanat does not cause a significant discharge of underground water, unlike a well, because the amount of water in the Qanat is proportional to the volume of the underground aquifer, and it utilizes the surplus of underground water. The Qanat is a living organism that balances the water level of underground aquifers even during severe droughts. The Qanat is an eco-technology that demonstrates the relationship between humans and the environment, and it adapts to geographical conditions. Asgharzadeh further suggests that the Qanat has a self-regulating, generative, and self-aware nature towards the environment, and it possesses degrees of intelligence and artificial intelligence. However, it should be noted that this idea has only been discussed in one article
Sources	Kowkabi 2021; Motiee et al. 2006; Hamidian et al. 2015; Jomehpour 2009; Endreny 2008; Radaei et al. 2021; Hosseini 2010; Sedghi and Zhan 2022; Delfani et al. 2021; Ebizadeh 2011; Tabatabaei and Khozeymehnezhad 2019; Laghaei et al. 2012; Nasiri and Mafakheri 2015; Jomehpour 2009; Asgharzadeh et al. 2017; Jomehpour 2009; Ebizadeh 2011; Labbaf Khaneiki 2019, 2016;
Theme	3- Clean Energy Generator
Explanation	The water mill uses the flow of water from the Qanat to move the mill wheel and grind wheat into flour. Additionally, wind deflectors were facilities that used the humidity of the Qanat and wind flow to cool buildings
Sources	Ahmadi, Nazarisamani, and Malekian 2014; Jomehpour 2009; Delfani et al. 2021; Tabatabaei and Khozeymehnezhad 2019
Theme	4- Protector of vegetation and animals
Explanation	The water infrastructure of Qanat in cities and villages promotes the formation and preservation of agricultural lands, gardens, green spaces, green corridors (along the network of streams), and green areas adjacent to dams and pools. In dry areas, the Qanat is considered the only aquatic habitat for fish, crabs, shrimps, etc
Sources	Radaei et al. 2021; Bouzarjomehri and Khatami 2018; Hashemzadeh Segherloo 2015a, b; Mansouri et al. 2010; Ramin and Doustdar 2019; Azh et al.2015; Ebizadeh 2011; Sadeghi et al. 2013; Abadian et al. 2017

achieved when they are initially addressed academically within the realm of infrastructure.

As previously mentioned, diverse approaches have been proposed from historical times to the present in the field of urban infrastructure. However, due to the diverse features of Qanat encompassing functional, physical, cultural, social, and economic domains, a comprehensive approach to classification is necessary. Therefore, the landscape infrastructure approach, which offers a holistic, comprehensive, and objective-subjective perspective by deeply connecting infrastructure with various tangible and intangible layers of the cities, while simultaneously considering functional, cultural, and aesthetic objectives for the infrastructure, (Mansoury and Alhashemi 2015; Rouse et al. 2013; Belanger 2009) is the most suitable choice for creating a comprehensive framework of Qanat features.

Consequently, the classification of features was initially conducted under the landscape infrastructure definition, organizing them into two main categories: tangible and intangible, relying on the conventional primary classification (environmental, cultural-social, economic). Subsequently, the triple objectives of landscape infrastructure (functional, identity-based, aesthetic) were incorporated as the third-level organizing factor in the final framework (See Fig. 9).

Conclusion

A semi-systematic review of the literature related to Qanat in various scientific disciplines reveals that Qanat possesses a wide spectrum of tangible and intangible features in environmental, cultural, social, and economic domains.

In addition to supplying water to settlements, Qanats are deeply intertwined with cultural and religious beliefs. They play a role in traditions, social ceremonies, naming practices, and even colloquial proverbs. A social network has developed around the construction and operation of Qanat water, shaping social roles and informal rules, strengthening social capital, and contributing to the formation of social classes. Moreover, Qanat water holds significant trade value and plays a crucial role in fostering

Table 7 economic features (source: authors)

Theme	1- Efficient
Explanation	Qanat is an efficient water supply system as it operates without the use of electricity, diesel, petroleum products, pumps, spare parts, or mechanical lifts. Furthermore, it excavates water with the lowest amount of evaporation only by gravity. In addition, the cost of maintaining the Qanat is less than one percent of its construction capital. Most published articles have mentioned this feature of Qanat in the introduction
Sources	Sedghi and Zahn 2022; Kowkabi 2021; Delfani et al. 2021; Naghedifar et al. 2020; Stiros 2006; Becket and Smith 1953; Endreny 2008; Hosseini et al. 2010; Jomehpour 2009; Beaumont 1971; Nasiri and Mafakheri 2015; Charbonnier and Hopper 2018; Radaei et al. 2021; Tabatabaei and Khozeymehnezhad 2019; Tabatabaei and Khozeymehnezhad 2019; Nadri and Abassi 2017
Theme	2- Property
Explanation	The Qanat has been regarded as an important economic resource in the past, and the Karizi civilization has unique economic characteristics. Farms irrigated by Qanat have played a pivotal role in Iran's economic and social prosperity. In addition, the water share of the Qanat is considered an asset that can be rented, bought, and transferred. It seems that participation in the construction of the Qanat was a form of investment even for people who are not active in the field of agriculture
Sources	Kowkabi 2021; Lightfoot 1996; Colonel and Noel 1944; Jomehpour 2009; Hosseini et al. 2010; Remini, Achour, and Albergel 2015; Labbaf Khaneiki 2020, 2019, 2016; Tabatabaei and Khozeymehnezhad 2019; Bouzarjomehri and Khatami 2018; Ebizadeh 2011
Theme	3- Related Businesses
Explanation	Moghni" is one of the most important jobs related to Qanat. Due to the necessity of their profession, Moghni has enjoyed social respect and high income. In the process of building a Qanat, many jobs are involved, including carpenters, stone cutters, potters, bucket makers, brewers, leather makers, blacksmiths, pick and hammer workers, pen makers, coil makers, hemp rope makers, and oilers. Additionally, roles have been defined in the Qanat exploitation system, where some work in exchange for receiving a larger share of water or cash from all partners in the irrigation system. These roles include Mirab, Sartaq, Qanat watchtower, Dashtban (Joghun or Juban), and Pey Oken
Sources	Labbaf Khaneiki 2020, 2019; Goes et al. 2017; Papoli Yazdi and Vosoghi 2019; Janebelahi 2019

Fig. 8 kish Qanat rehabilitation project (source, www.tasnimnews.com)

various businesses and industries related to Qanat construction and operation. In dry and semi-arid regions of Iran, Qanat represent the main, and sometimes only, source of water supply, contributing to the preservation of vegetation cover and wildlife. Wells and underground facilities, along with the distributary network of water, have had a significant impact on shaping the spatial structure of cities. Public land use, water facilities, neighborhood boundaries, green and agricultural patches, all have been influenced by the presence of Qanat in cities reliant on this water system.

Qanat represent a water infrastructure that extends beyond a mere water supply system and fulfills roles in various social, economic, and cultural layers. Therefore, the landscape infrastructure approach seems to be the most suitable option for classifying Qanat features due to its tangible-intangible nature and comprehensive perspective. By considering the functional, identity-based, and aesthetic values of Qanat, the landscape infrastructure approach can offer a comprehensive image of this phenomenon.

This comprehensive image of Qanat, as a general framework, can be utilized in the study and planning of Qanat revitalization. Having an overarching view of this phenomenon allows for the consideration of all tangible and intangible values of Qanat and their interconnectedness as a coherent system. The classification system, guided by the landscape infrastructure approach, helps researchers identify various aspects to explore and ensures that values, especially intangible ones, are not overlooked inadvertently. This comprehensiveness in studying Qanat ensures the preservation of this valuable heritage with a holistic perspective at the implementation level. Without safeguarding the meaningful values, Qanat might become mere sets of empty wells and passages devoid of significance, with little justification for their preservation and maintenance.

Finally, provided model serves as a roadmap for initiating a comprehensive study of case study examples. It assists researchers and decision-makers in understanding the characteristics they need to identify in a Qanat revitalization project.

Consequently, these Qanat features can be revitalized within contemporary cities to the extent possible.

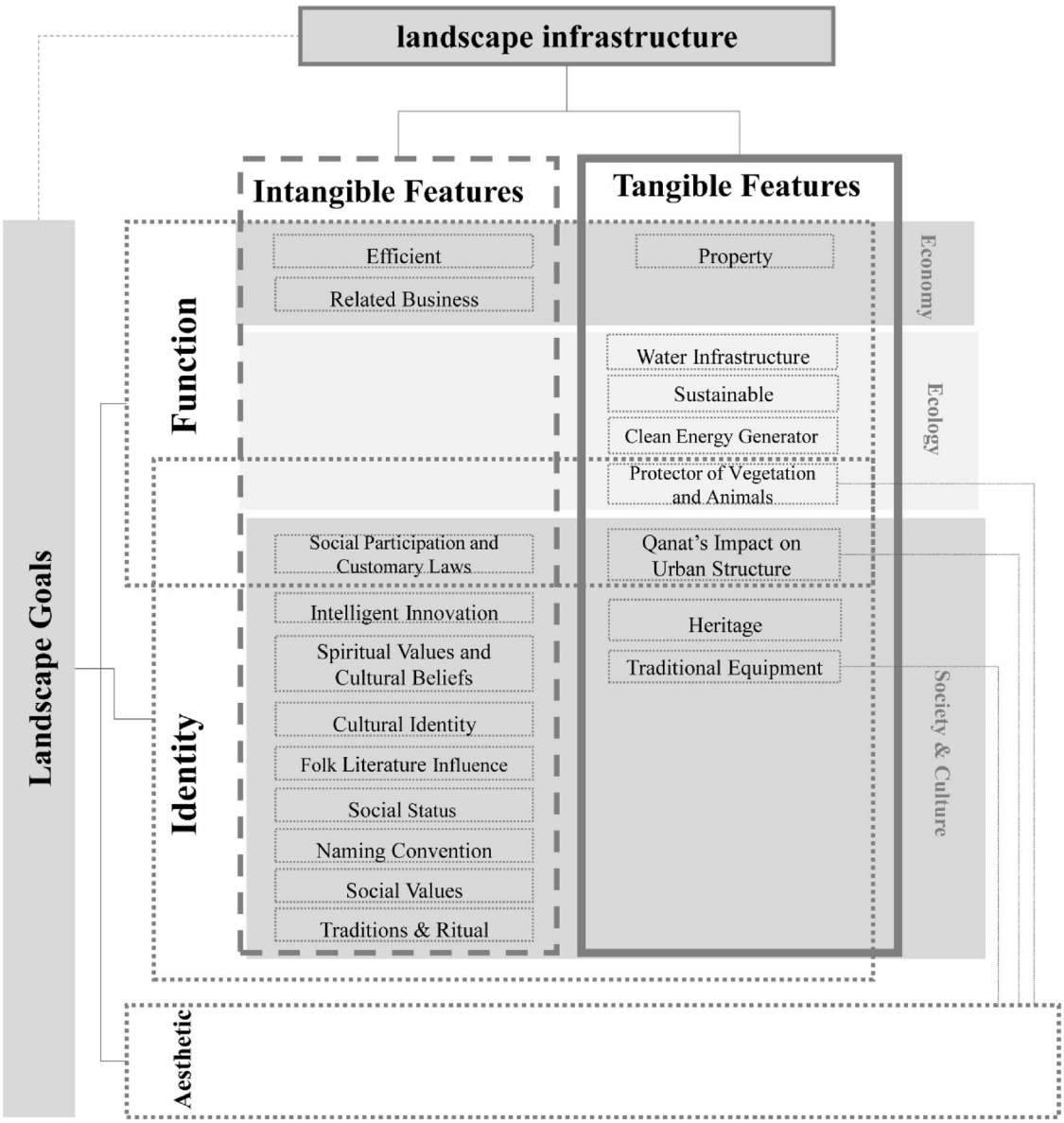

Fig. 9 Qanat's Features Classification based on the landscape infrastructure definition. (Authors)

Studying various Qanats using this comprehensive model helps ensure that certain aspects of Qanats are not inadvertently overlooked. A comprehensive understanding of each Qanat's geographical and cultural uniqueness is essential groundwork for their proper and sustainable restoration. Once the different characteristics are identified, practical and executable steps can be taken for their revival. However, without knowledge of these features, planning for their restoration will be virtually impossible.

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Recommendation
The model presented in this research can serve as a preliminary template for studying specific cases. City managers, prior to commencing decision-making regarding a Qanat, can use this model to identify the desired Qanat features. Subsequently, through scientific methods, they can undertake canal regeneration. Furthermore, researchers can complement this study by employing quantitative, qualitative, and creative research methods to explore tangible and intangible Qanat characteristics.

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All authors contributed to conceptualizing the study. Additionally, they all participated in the manuscript's review and revision process. Furthermore, SA

and MA were responsible for drafting the primary manuscript, while SAM and MH conducted the manuscript's editing.

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Declarations

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