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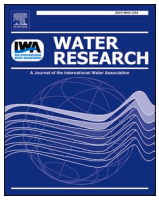

# Reviving the forgotten legacy: Strategies for reviving qanats as sustainable solutions for agricultural water supply in arid and semi-arid regions

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ABSTRACT

In semi-arid and arid regions, qanats are a vital water source for agricultural needs. However, many communities are abandoning these traditional and sustainable water supply systems in favor of modern and more productive methods. Consequently, this research aimed to identify the most effective approaches for rejuvenating qanats in the dry and semi-arid areas of Razavi Khorasan province, Iran. To accomplish this goal, a comprehensive strategy was employed by merging the Strengths, Weaknesses, Opportunities, and Threats (SWOT, Best-Worst Method (BWM), and the Weighted Aggregated Sum Product Assessment (WASPAS).Based on interviews with experts in water resources and SWOT analysis, 27 factors affecting the restoration of qanats were identified and weighted with BWM. The results of BWM-WASPAS highlight the crucial role of a holistic approach in reviving qanats. The study findings reveal that the highest scores were obtained by the strategies reforming water governance policies to prioritize sustainable indigenous water resources (SO1) and establish an independent institution for qanat restoration (WT7). Conversely, educational (ST1), informational (SO3), and research (WO4) strategies concerning the revival of qanats were categorized as intermediate priorities. Lastly, strategies associated with farm-level support policies were assigned lower priorities. Accordingly, it is recommended that policymakers in Mashhad give priority to macro-level and institutional policies concerning qanat restoration, considering the current state of indigenous water resources. Additionally, a continued emphasis on research policies and farm-level initiatives is advised.

## 1. Introduction

The utilization of local knowledge, derived from centuries of experience, plays a vital role in the sustainable management of water resources (Bakhshi et al., 2021; Marlow et al., 2013; Fu et al., 2022). In addressing water scarcity, our predecessors demonstrated a commitment to sustainability and effectiveness by employing various methods. Drawing upon their native knowledge, they pioneered innovative systems, most notably the construction of qanats. These practices exemplify their resourcefulness and ingenuity in managing water resources (Mansouri Daneshvar et al., 2023; Amindin at al., 2024). Qanats are underground channels that are designed to transport water from an underground aquifer to the surface. This system comprises several components, including an underground tunnel or gallery for water collection and conveyance, a mother well, shaft wells, an outlet, and surface channels for water distribution (Mansouri Daneshvar et al., 2023). Qanats that incorporate vertical shafts, resembling wells, offer several advantages. These include minimizing water loss through evaporation, increasing resilience against natural disasters, and ensuring consistent water quality and quantity (A. Kazemi et al., 2022). This ancient Persian technology has been used for thousands of years and is still in use in many countries, such as Iran, Japan, China, Pakistan, Afghanistan, Morocco, Spain, Greece, Chile, USA, Peru, Mexico, Oman, Syria, Iraq, Azerbaijan, and North Africa (Shirzadi et al., 2017; Samani

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et al., 2022; Hojat et al., 2023). The United Nations Educational, Scientific, and Cultural Organization (UNESCO) recognizes the immense importance of qanats as a human legacy and their crucial role in advancing sustainable groundwater management in arid areas. Therefore, eleven of these remarkable structures in Iran have been included in the UNESCO World Heritage List, underscoring their cultural, social, political, and physical significance (Mousazadeh et al., 2023).

Aqueducts have been formally acknowledged by the Food and Agriculture Organization of the United Nations (FAO) as Globally Significant Agricultural Heritage Systems (GIAHS). According to FAO, aqueduct systems embody a distinctive and comprehensive approach to sustainable land and water management, as well as the preservation of agricultural biodiversity. Managing aqueducts involves leveraging indigenous knowledge and wisdom to ensure the sustainable utilization of water resources while upholding a harmonious balance with nature and culture (FAO, 2018).

Qanats are technologically significant for various reasons (e.g., transporting water over long distances, preventing evaporation in dry weather). These ancient water supply systems efficiently harvest and distribute water over long distances in arid and semi-arid regions, addressing critical water scarcity challenges (Sanaan Bensi, 2020). Utilizing gravity-driven flow, qanats transport water from higher elevations to lower ones through gently sloping channels. This minimizes the need for external energy inputs, making them a sustainable and energy-efficient water transport technology (Samani et al., 2023). The subterranean nature of qanats also aids in temperature regulation, reducing evaporation losses and ensuring a reliable water supply for agricultural and domestic use. Their minimal environmental impact, adaptability to local conditions, and cultural heritage further contribute to their importance (Chathuranika et al., 2022). Recent studies, such as Ghobadian et al. (2017), Mohammadi et al. (2019), and A. Kazemi et al. (2022), highlighted the enduring relevance of qanats in contemporary water resource management. These studies demonstrate that qanats, an ancient and sustainable system, have facilitated the harvesting of water from underground aquifers for centuries in arid and semi-arid areas.

Qanats demonstrate a remarkable level of sustainability, with some ancient systems still in use after centuries (Khodapanah et al., 2021). Their adaptability to various geological and hydrological conditions underscores their versatility, allowing communities to implement qanats in diverse landscapes (Samani et al., 2023). By tapping into underground aquifers, qanats provide a reliable alternative to surface water sources, reducing dependency on scarce or seasonally variable water supplies (Fahmy et al., 2023). Khodapanah et al. (2021), Fahmy et al. (2022), and Bagheri et al. (2023), further underscores the ongoing significance of qanats as enduring and sustainable technologies in the face of evolving water management challenges. These studies indicated that qanats is a technique adapted to climate change.

In contrast to contemporary mainstream hydraulic technologies, ancient qanats stand out as a sustainable and energy-efficient water supply system. While modern methods often rely on energy-intensive technologies like electric pumps for water extraction and transportation, qanats operate on a gravity-driven system, exemplifying a more environmentally friendly and resilient approach (Ghahraman et al., 2020). The inherent adaptability of qanats to diverse geological conditions and their ability to function without continuous energy inputs further emphasize their unique advantages in comparison to some contemporary alternatives. The subterranean structure of qanats minimizes water evaporation, a common issue in open-channel systems, ensuring a more efficient utilization of water resources (Barani et al., 2021). Some recent studies (Ghahraman et al., 2020; Barani et al., 2021) highlighted the importance of considering traditional qanats alongside modern hydraulic technologies. Therefore, recognizing the significance of qanats in terms of energy efficiency, environmental impact, and adaptability underscores the imperative of conserving and integrating these traditional water supply systems into contemporary water management strategies.

Qanats have proven to be useful even with the advent of new pumping technologies (Samani et al., 2022). This recognized world heritage has been instrumental in the development of civilizations in dry and semi-dry areas where the availability of continuous surface water sources is restricted. Moreover, qanats remain the primary suppliers of water for agricultural purposes in these regions (Maghrebi et al., 2023). Nevertheless, in recent decades, qanats have faced significant challenges (factors such as floods and earthquakes, recurring droughts, rising water demand, and government backing for contemporary water supply systems) due to increasing human pressures and natural factors (Maghrebi et al., 2023). Societies in the Middle East have abandoned qanats and replaced them with more productive modern systems to meet the growing demand for water (Eslamian et al., 2016; Megdiche-Kharrat et al., 2019; Akbari et al., 2024). The declining significance of qanats as a sustainable method for water extraction in arid and semi-arid regions is indeed a matter of concern. This decline can potentially have far-reaching consequences for sustainable development, especially in the agricultural sector within these regions. The reliance on qanats for water supply has historically played a crucial role in supporting agricultural activities in arid and semi-arid areas where water scarcity poses a significant challenge. However, as the importance of qanats diminishes, alternative solutions and strategies must be sought to ensure the sustainable development of these regions and the viability of agricultural practices. Addressing this issue requires a comprehensive approach that considers both conservation efforts and the exploration of innovative water management techniques suitable for arid and semi-arid environments. Qanats should be considered as sustainable solutions to address the global water problem and inequity in access to fresh water. They must be preserved, reconsidered, and resurrected as solutions for socially equitable management and intelligent groundwater acquisition that enable sustainable resource use (Megdiche-Kharrat et al., 2016, 2019). Hence, it is crucial to identify and establish optimal approaches to rehabilitate qanats, considering various factors that influence this ancient water supply system.

Table 1 presents a summary of previous studies that have employed different numerical and descriptive methods, such as statistical equations, literature reviews, laboratory experiments, and artificial intelligence, to explore qanat restoration. However, these methodologies have not fully accounted for all the factors that influence the restoration process, nor have they adequately addressed the interconnectedness among these factors and the ambiguities faced in actual circumstances. Furthermore, the assessment of individuals responsible for making decisions in the restoration procedure has frequently been disregarded. Another critical aspect to consider is the need for region-specific strategies, as diverse weather conditions exist across different geographic areas.

To overcome these research deficiencies and formulate efficient qanat revival strategies, this investigation suggests a merged technique that integrates the Strengths, Weaknesses, Opportunities, and Threats (SWOT) examination with the multi-criteria decision-making (MCDM) procedure. The aim of this research is to recognize the elements that contribute to the prosperous rejuvenation of qanats and to create and prioritize plans for their revival. The mixture of strategies that has been decided upon consists of the SWOT analysis, Best-Worst Method (BWM), and the Weighted Aggregated Sum Product Assessment (WASPAS). It has been demonstrated that combining several methods leads to higher accuracy than using each method individually (Barbara et al., 2023). In a combined approach, factors contributing to the revival of qanats can be comprehensively considered. These methods were chosen for their compatibility with the research goals and the requirement for a comprehensive assessment methodology. The SWOT analysis is a decision-making tool that assesses the advantages, drawbacks, possibilities, and risks linked to the revival of qanats (Esfandiari et al., 2022). BWM is a reliable MCDM technique used to weigh decision-making criteria (Firoozzare et al., 2023). In comparison to other methods such as Analytic Hierarchy Process (AHP), BWM provides more dependable

**Table 1**
Literature related to the qanat.

| Authors | Purpose of the study | Method used | Results |
|---|---|---|---|
| A. Kazemi et al. (2022) | Assessment of health risks associated with total chromium in the historical water supply system of the qanat. | Laboratory | The total chromium (CrT) in the qanats of South Khorasan Province in Iran is higher than the permissible limit of the World Health Organization, as a result of which the risk of cancer for residents is high. |
| Sedghi and Zhan (2022) | On the discharge variation of a qanat | Analytical modeling | The discharge of the qanat depends on the hydraulic and geometrical parameters of the aquifer. |
| Kowkabi (2021) | Revival of urban qanats | Qualitative studies | The use of this biological infrastructure (qanat) in the development and regeneration of the city will be possible and positive. |
| Maghrebi et al. 2023 | Investigation of land-use changes and losses of qanats | Remote sensing | The most remarkable qanat-impacting land-use changes occurred in farming and metropolitan regions. |
| Nasiri and Mafakheri (2015) | Revisit of sustainable ancient water supply systems (qanats) | Analytical | Arid and semi-arid regions should preserve this ancient technology as a tremendous human heritage and consider it a sustainable method for managing groundwater. |
| Goes et al. (2017) | The current state of the qanats in the Helmand River Basin | Review | Although renovating qanats is more costly than digging new wells, qanats are part of Afghanistan's national heritage. |
| Naghibi et al. (2018) | Modeling the potential of underground water based on the location of the qanat | Artificial neural networks and multivariate adaptive regression | The location of the qanat can be used as a suitable indicator to evaluate the potential of underground water. |
| Wessels (2005) | The revival of ancient water tunnels in the desert | Analytical | Qanat revival is determined by social, political, geographical, and hydrological factors. |

results. Furthermore, this method requires less comparative data (Firoozzare et al., 2023). Finally, WASPAS, a novel and effective MCDM method, is employed to assess the weighting of strategic alternatives. By utilizing the WASPAS Model, we can achieve a more accurate and comprehensive evaluation of our data. In generally, this study uses the SWOT-BWM-WASPAS integrated approach because:

1. Comprehensive assessment: This study aims to develop an integrated approach that can comprehensively consider all the factors influencing the revival of qanats. Combining SWOT analysis, BWM, and WASPAS identifies internal and external factors (SWOT), determines the weights and importance of each factor (BWM), and prioritizes alternative revival strategies (WASPAS). This integrated approach allows for a more thorough and holistic evaluation of the problem.

2. Compatibility and accuracy: Combining multiple methods results in higher accuracy than using each method individually (Barbara et al., 2023). The selected methods are compatible with each other and can be combined effectively to enhance the overall accuracy and reliability of the results.

3. Addressing research gaps: Using numerical or descriptive methods in previous studies (e.g., Sedghi and Zhan, 2022; Nasiri and Mafakheri, 2015) did not fully account for all the factors influencing the revival process. They also inadequately addressed the interconnectedness of these factors and the ambiguities faced in real-world situations. For this reason, the combined approach of SWOT-BWM-WASPAS is chosen to overcome these research deficiencies and formulate efficient revival strategies.

4. Suitability for the research objectives: These methods are chosen for their compatibility with the research goals and the requirement for a comprehensive assessment methodology. SWOT analysis is suitable for identifying strengths, weaknesses, opportunities, and threats. BWM is a reliable multi-criteria decision-making (MCDM) technique for weighting criteria, and WASPAS is an effective MCDM method for evaluating and prioritizing alternative strategies.

5. Advantages of individual methods: The study highlights specific advantages of each method which contributes to their selection. For instance, BWM requires less comparative data than other methods like AHP, and WASPAS combines the strengths of the Weighted Sum Model (WSM) and the Weighted Product Model (WPM) for effective decision-making.

As a result, the present study contributes to the literature on the topic in three ways. First, it determines the strategies, based on the strengths, weaknesses, opportunities, threats, and factors of the societies, for the revival of qanats. Second, the interdependence of the components is taken into account. Third, as a result of the varying geographical circumstances in various areas, this research centers on a single province, namely, Razavi Khorasan, located in Iran. The rest of this study is organized as follows: Section 2 describes the materials and methods used in this investigation, Section 3 presents the findings and discussion of the study, and Section 4 recapitulates the conclusions derived from the research.

## 2. Materials and methods

### 2.1. Study area

Iran currently holds the record for the most operating qanats in the world, boasting a staggering 37,000. These qanats extract roughly seven billion $m^3$ of groundwater each year (Bostani and Ansari, 2013; Ghasemi et al., 2021). The investigation was carried out in Razavi Khorasan province (Fig. 1), a parched and semi-arid area located in the north-eastern part of Iran (Esfandiari Bahraseman et al. 2024). This province alone accounts for 16.5 % of Iran's total qanats, making this indigenous technology a crucial source of water supply for agriculture, drinking water in villages, and even urban areas (Khorasan Razavi Regional Water Company, 2019). Over the past few decades, historical qanats in the region have either deteriorated significantly or are at risk of disappearing entirely, mainly because of increased water demand, the increase in deep and partially deep wells, inadequate upkeep, failure to adhere to privacy rules, contamination, inundation, and seismic activity, as observed by Maghrebi et al. (2023). Over the last five decades, it is estimated that 95 % of the subterranean water channels in this region have been demolished, leading to ecological, financial, and communal outcomes (Maghrebi et al., 2023). Reviving the qanats in the area may offer a resolution to some of these issues. Water policymakers believe that this ancient technology should be preserved not only as a cultural heritage but also as a sustainable groundwater management method in arid and semi-arid regions (Laghaei et al., 2012). It is crucial for decision-makers in this area to possess a thorough comprehension of the advantages, limitations, possibilities, and risks linked to the resurgence of qanats. Additionally, they should develop strategies and plans for the

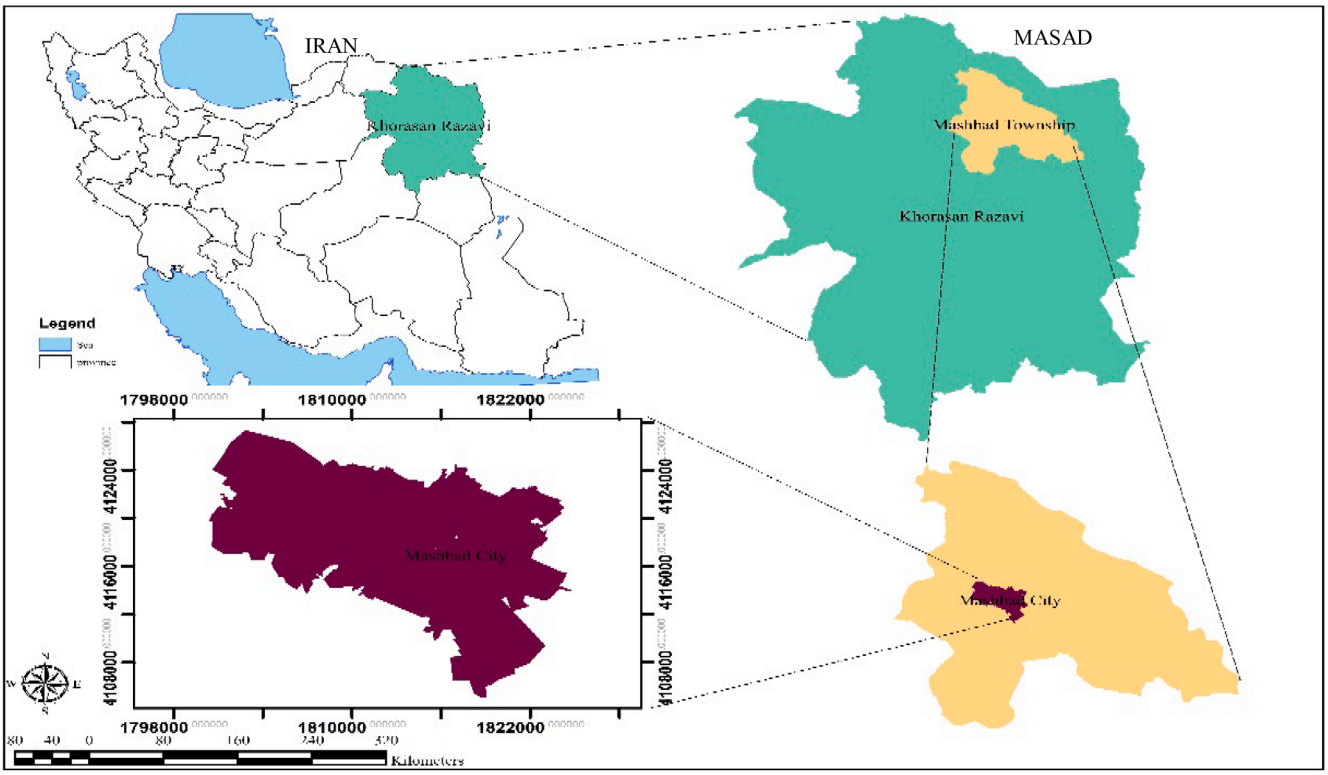


**Fig. 1.** The geographic position of the research site in Razavi Khorasan province, Iran.

revitalization of these traditional water systems. By doing so, they can effectively harness the potential benefits of qanats while addressing any challenges or risks they may pose.

### 2.2. Selection of participants

Qualitative research aims for deep understanding without generalization and selecting participants strategically. Quantitative research prioritizes random selection for equal representation and generalizability. In quantitative research, data saturation is typically achieved through the collection and analysis of a sufficient amount of data to ensure that the findings are reliable and valid (Saunders et al., 2018), While data saturation in qualitative research refers to the point at which no new information or themes are emerging from the data collected. It indicates that enough data has been collected to fully understand the research topic and that further data collection is unlikely to yield any new insights (Hennink and Kaiser, 2021). Researchers rely on mental processes to choose the sample size (Braun and Clarke, 2021).

Based on the mental processes, researchers determine the sample size for their study. Aghasafari and colleagues (2020) engaged in interviews with a panel of 20 experts. Takeleb et al. (2020) conducted 25 interviews, Balezentis et al. (2021) conducted 21 interviews, and Esfandiari et al. (2022) conducted 20 interviews, while Kolagar et al. (2019) conducted only 4 interviews. Accordingly, this study selected 5 specialists. A qualitative study was conducted aimed at gathering comprehensive information about the phenomenon under study (revitalization strategies of qanats). Based on this, experts were selected for ranking. The purpose of the study was to identify strategies to revive qanats in Mashhad.

### 2.3. Methodology

#### 2.3.1. SWOT-BWM-WASPAS integrated approach

The research utilized a blend of SWOT examination, i.e., Best Worst Method (BWM) and Weighted WASPAS, to pinpoint the elements influencing the revival of qanats, ascertain the significance of each SWOT sub-factor, and rank alternative resolutions (Fig. 2). Firstly, a SWOT examination was carried out to recognize the internal and external elements impacting the revival of qanats. Secondly, BWM was employed to allocate importance to each SWOT sub-factor. In conclusion, the WASPAS technique was utilized to rank different solutions according to their effectiveness in meeting various criteria. Below is a concise explanation of the approaches employed.

*2.3.1.1. SWOT analysis.* The SWOT assessment is a potent instrument for recognizing and examining the advantages, disadvantages, prospects, and challenges of a corporation or venture. By scrutinizing both the internal and external surroundings, the SWOT framework aids decision-makers in formulating efficient plans to enhance the system. In the SWOT matrix, internal factors, such as strengths and weaknesses, are typically identified in the top half of the matrix. In addition, external factors, such as opportunities and threats, are typically identified in the bottom half (Cacal et al., 2023). The intersections of these factors create four general states, including SO, ST, WO, and WT, which represent different types of strategies that can be developed to address the identified issues (Fig. 3).

The SO strategy (offensive) focuses on leveraging internal strengths to maximize the benefits of external opportunities. This approach involves actively pursuing growth and expansion initiatives, capitalizing on market trends, and making investments in innovation and technology to maintain a competitive edge. By adopting an offensive strategy, organizations aim to proactively shape their industry and achieve significant advancements. The ST strategy (competitive) emphasizes using internal strengths to mitigate external threats. This strategy involves developing a competitive edge by improving operational efficiency, building brand reputation, and creating customer loyalty programs.

The WO strategy (conservative) is designed to address internal weaknesses by taking advantage of external opportunities. This strategy involves investing in new technologies, products, and services that align with the organization's core competencies and leveraging partnerships

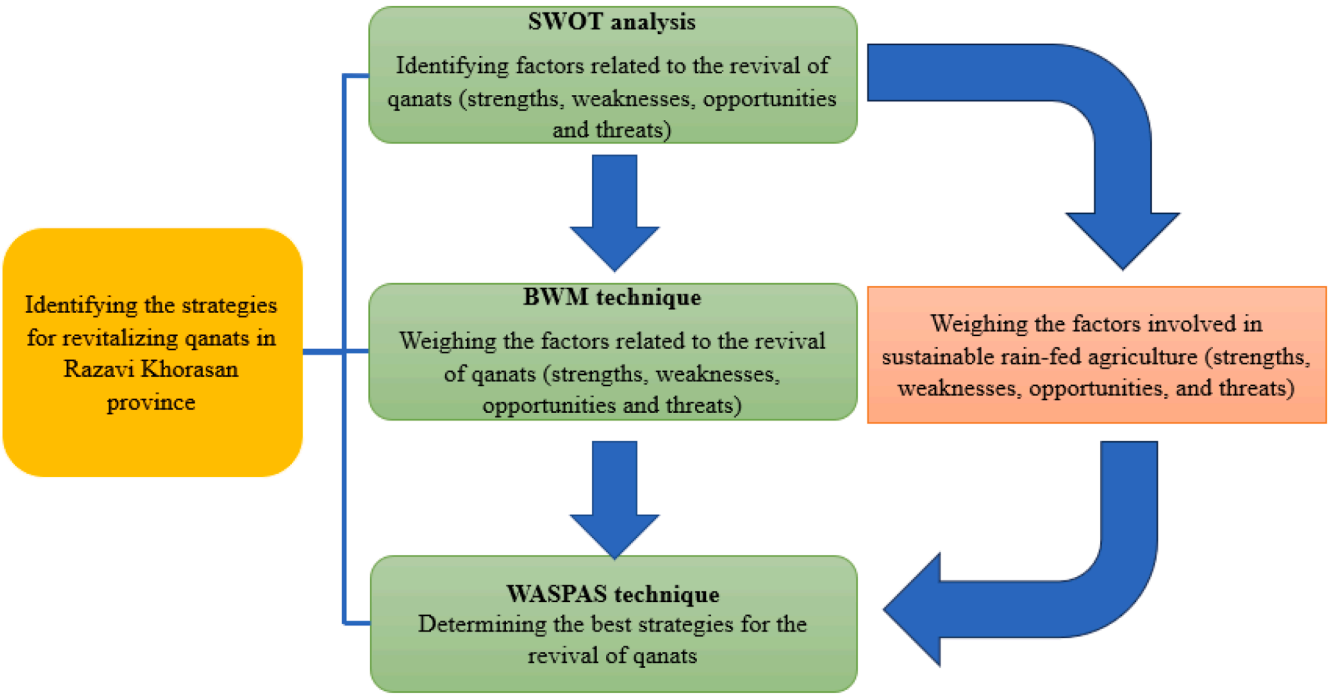


**Fig. 2.** The SWOT-BWM-WASPAS framework was used.

| | STRENGTHS<br>1.<br>2.<br>3.<br>4. | WEAKNESSES<br>1.<br>2.<br>3.<br>4. |
|---|---|---|
| OPPORTUNITIES<br>1.<br>2.<br>3.<br>4. | Opportunity-Strength (OS) Strategies<br>Use the strengths to take advantage of opportunities<br>1.<br>2. | Opportunity-Weakness (OW) Strategies<br>Overcome weaknesses by taking advantage of opportunities<br>1.<br>2. |
| THREATS<br>1.<br>2.<br>3.<br>4. | Threat-Strength (TS) Strategies<br>Use strengths to avoid threats<br>1.<br>2. | Threat-Weakness (TW) Strategies<br>Minimize weaknesses and avoid threats<br>1.<br>2. |

**Fig. 3.** The structure of SWOT matrix.

and collaborations to increase market share.

The WT strategy (defensive) focuses on minimizing internal weaknesses and mitigating external threats. This strategy involves reducing costs, optimizing operational processes, and investing in employee training and development to improve performance and productivity.

Overall, the SWOT matrix provides a comprehensive framework to analyze the internal and external factors that impact an organization and developing effective strategies to address them (Esfandiari et al., 2022).

*2.3.1.2. BWM technique.* BWM is a novel technique developed by Jafar Rezaei in 2016 to address the limitations and drawbacks of other methods that rely on pairwise comparisons. One of the main advantages of this multi-indicator decision-making method is that it requires less comparative data compared to other methods. Additionally, it is compatible with other decision-making techniques for combined use and can be applied to problems with qualitative, quantitative, and mixed data (Rezaei et al., 2016; Torkayesh et al., 2021). Additionally, BWM produces more robust comparison results, leading to more dependable answers. Outlined below are the steps involved in using the BWM technique:

Step 1: The initial stage is to establish a collection of standards indicated as C1, C2, …Cn, that will be utilized for decision-making or

prioritization of objectives.

Step 2: The second step involves identifying the most desirable and important criteria, as well as the least desirable and unimportant criteria. In this phase, the decision maker typically identifies the optimal and least favorable criteria. No evaluations are conducted in this segment.

Step 3: The next stage involves establishing the inclination of the top criterion in relation to other criteria utilizing a scale ranging from 1 to 9. This enables a numerical evaluation of the comparative significance of each criterion. The outcomes of the top criteria compared to other criteria may be as follows:

$$A_B = (a_{B1}, a_{B2}, \ldots, a_{Bn}) \tag{1}$$

Where $a_{Bj}$ indicates the degree of priority of the best criterion B in comparison with criterion j. Therefore: $a_{BB} = 1$

Step 4: The fourth phase entails evaluating the level of favorability of each criterion compared to the least favorable criterion, as well as employing a range of 1 to 9. The resulting array can be utilized for the purpose of decision-making. In this instance, the resultant array may appear as follows:

$$A_w = (a_{1w}, a_{2w}, \ldots, a_{nw})^T \tag{2}$$

Where $a_{jw}$ indicates the degree of priority of criterion j compared to the worst criterion. Therefore: $a_{ww} = 1$

Step 5: In the fifth stage, i.e., the last stage, the magnitude of each criterion is computed using an optimization model. The agreement rate is also computed based on the magnitudes assigned to each criterion. The ideal magnitude of the criteria is displayed as follows:

$$w_1^*,\ w_2^*,\ \ldots,\ w_n^* \tag{3}$$

The following formulas are used to calculate the optimal weight:

$$\begin{aligned} &\min \max_j \left\{ \left| \frac{w_B}{w_j} - a_{Bj} \right|, \left| \frac{w_j}{w_w} - a_{jw} \right| \right\} \\ &s.t. \\ &\sum_j w_j = 1 \\ &w_j \geq 0,\ for\ all\ j \end{aligned} \tag{4}$$

In summary, these steps are used to establish a set of criteria, evaluate their importance, and compare them to one another in order to make informed decisions. The weight of each criterion is then calculated using an optimization model, and the compatibility rate is determined based on the assigned weights (Rezaei et al., 2016).

*2.3.1.3. WASPAS technique.* The WASPAS approach is a method to make decisions based on multiple criteria and combines the WSM and the WPM in order to choose the most suitable alternatives. The method consists of multiple stages, such as standardizing the decision matrix, evaluating the relative importance of the options using the WSM and WPM approaches, computing the shared criterion, and selecting the optimal λ value based on the standard deviation. The normalization process involves using Eqs. (5) and 6 to convert the decision matrix into a normalized matrix.

$$\overline{X}_{ij} = \frac{X_{ij}}{\max_i X_{ij}} \quad for\ beneficial\ criteria \tag{5}$$

$$\overline{X}_{ij} = \frac{\min_i X_{ij}}{X_{ij}} \quad for\ non-beneficial\ criteria \tag{6}$$

The relative importance of the options is then computed using Eqs. (7) and 8, which considers the weights of the criteria. The standard measure is subsequently computed using Eq. (9), which assigns the same importance to both the WSM and WPM approaches.

$$Q_i^{(1)} = \sum_{j=1}^{n} \overline{X}_{ij} W_j \tag{7}$$

$$Q_i^{(2)} = \prod_{j=1}^{n} \left(\overline{X}_{ij}\right)^{wj} \tag{8}$$

$$Q_i = 0.5 Q_i^{(1)} + 0.5 Q_i^{(2)} = 0.5 \sum_{j=1}^{n} \overline{X}_{ij} W_j + 0.5 \prod_{j=1}^{n} \left(\overline{X}_{ij}\right)^{wj} \tag{9}$$

To rank the alternatives, the Landau formula (Eq. (10)) is used to calculate the relative significance of each alternative.

$$Q_i = \lambda Q_i^{(1)} + (1-\lambda) Q_i^{(2)} = \lambda \sum_{j=1}^{n} \overline{X}_{ij} W_j + (1-\lambda) \prod_{j=1}^{n} \left(\overline{X}_{ij}\right)^{wj} \quad , \quad \lambda = 0, 0.1, \ldots, 1 \tag{10}$$

The optimal λ value is then determined using Eqs. (11) to 14 based on the standard deviation. The options are ultimately ordered based on their Q values, with the highest Q value indicating the optimal choice.

$$\lambda = \frac{\sigma^2(Q_i)}{\sigma^2(Q_i) + \sigma^2(Q_i)} \tag{11}$$

$$\sigma^2(Q_i) = \sum\nolimits_{j=1}^{n} x_{ij} w^2 \sigma^2(X_{ij}) \tag{12}$$

$$\sigma^2(Q_i) = \sum\nolimits_{j=1}^{n} \left[ \frac{n\left(X_{ij}\right)^{wj} \times w_{ij}}{\left(X_{ij}\right)^{wj} \left(X_{ij}\right)^{(i-wj)}} \right] \sigma^2 \tag{13}$$

$$\sigma^2\left(X_{ij}\right) = \left(0.05 X_{ij}\right)^2 \tag{14}$$

In general, the WASPAS technique is a successful approach to choose the optimal options using various factors. Its integration of the WSM and WPM methods aids in enhancing the precision and effectiveness of the decision-making procedure (Zavadskas et al., 2016; Deveci et al., 2022).

## 3. Results and discussion

### 3.1. SWOT-BWM results

Based on field studies, library research, interviews with experts, and related literature, internal and external factors associated with the revival of qanats were identified (the third column in Tables 2 and 3). Table 2 displays the results of the assessment of the grid of internal elements, encompassing the advantages and disadvantages of revitalizing qanats in Razavi Khorasan province utilizing BWM. Among the seven strengths ranked by the community of experts, factor S2, i.e., "maintaining the hydrological balance of the aquifer," ranked the highest, with 0.2666 points. Experts in this study believe that maintaining the hydrological balance of aquifers is the most crucial strength of qanats in Razavi Khorasan province. In high-water conditions, qanats function as overflow channels, whereas in low-water conditions, they limit water discharge and adjust to the conditions of the aquifer. Due to this fact, qanats can play a vital role in maintaining water resources and providing irrigation in arid and semi-arid areas. The study conducted by Tabatabaei and Khozymehnezhad (2017) identified the maintenance of hydrological balance in the aquifer as a significant advantage of qanats. This discovery aligns with the findings of the current research. Out of the seven shortcomings identified, the highest ranking was attributed to the absence of recognition for the upkeep and restoration of qanats (W2), with a score of 0.227. The experts in this study believe that qanats require regular maintenance. However, one significant challenge in the revival of qanats is that the smallholder farmers who own these structures often face financial constraints that hinder proper maintenance. Due to limited financial resources, many qanats have been inadequately

**Table 2**
Evaluation Matrix of Internal Factors for Qanat Revival.

| | SWOT factors | SWOT sub-factors | Weight |
|---|---|---|---|
| Strengths (S) | S1 | The low cost of water in comparison to other extraction methods | 0.108 |
| | S2 | The maintenance of the aquifer's hydrological balance | 0.266 |
| | S3 | No need for energy | 0.139 |
| | S4 | The existence of native knowledge of drilling and reconstruction of qanats in the province | 0.093 |
| | S5 | A large number and proper distribution of qanats in the province | 0.162 |
| | S6 | The long useful life of the qanat | 0.141 |
| | S7 | Being valuable historically and culturally and consistent with the indigenous conditions of the region (province) | 0.092 |
| Weakness (W) | W1 | The lack of specialized labor associated with the qanat | 0.186 |
| | W2 | The lack of funds to maintain qanats | 0.227 |
| | W3 | The lack of water control of the qanat in non-agricultural seasons | 0.094 |
| | W4 | The sensitivity of the qanat to changes in groundwater levels | 0.182 |
| | W5 | High initial costs of reviving qanats | 0.105 |
| | W6 | Being smallholders and qanat shareholders | 0.124 |
| | W7 | Separation of partnerships related to qanats due to differences between shareholders, old age of shareholders, etc. | 0.081 |

**Table 3**
Evaluation matrix of external factors of qanat restoration.

| | SWOT factors | SWOT sub-factors | Weight |
|---|---|---|---|
| Opportunities (O) | O1 | The emergence of new technologies | 0.183 |
| | O2 | High capacities of tourism in the province | 0.183 |
| | O3 | The existence of cheap labor in the villages | 0.092 |
| | O4 | Increasing the attention of the scientific community to indigenous knowledge | 0.178 |
| | O5 | Emphasis on the restoration, preservation, and maintenance of qanats by international conventions | 0.262 |
| | O6 | The possibility of attracting private sector capital | 0.101 |
| Threats (W) | T1 | Successive droughts | 0.242 |
| | T2 | Disproportionate government support and legal weaknesses regarding qanats | 0.103 |
| | T3 | Non-cooperation between relevant organizations | 0.109 |
| | T4 | The incidence of environmental catastrophes such as deluges and seismic activities | 0.155 |
| | T5 | Failure to respect the privacy of qanats | 0.228 |
| | T6 | Increase in the migration of villagers to cities | 0.080 |
| | T7 | Misconceptions about indigenous knowledge of qanats | 0.084 |

maintained, leading to their gradual deterioration and eventual destruction. This situation highlights the need for targeted support and investment to ensure the sustainable upkeep of these vital sources of renewable native water. The present study's results correspond with previous research, particularly Ghasemi et al. (2021), which emphasized the lack of monetary assistance as a notable factor in the decline of aqueducts.

The results of the BWM approach used to evaluate the matrix of external factors are presented in Table 3. According to the findings of this research, the highest priority among the seven identified opportunities, as determined by the experts, was given to the emphasis of international conventions on the revitalization, preservation, and maintenance of qanats (O5). This priority is reflected in a score of 0.262. According to the opinions of the experts, the support of international organizations such as UNESCO and FAO for qanats is a critical opportunity to revive this sustainable and renewable local resource. UNESCO offers spiritual and financial support to many countries for the development and protection of qanats. In their research, Laghaei et al. (2011) considered the support of international conventions for indigenous knowledge technologies as a crucial opportunity for the revival of the qanat system. Based on the analysis of the seven identified threats, it was found that successive droughts (T1) received the highest score of 0.241. Droughts have caused a significant decrease in the underground water supply, leading to the drying up or reduced water levels of qanats that drain the dynamic part of the underground aquifers. The current study's results align with the investigation carried out by Ghasemi et al. (2021), which recognized drought and depleting groundwater levels as notable challenges to the revival of qanats.

### 3.2. WASPAS results

After determining the internal and external factors associated with reviving qanats and scoring them using BMW, practical strategies for reviving qanats were derived (Table 4). Next, the WASPAS technique was used to prioritize this strategy. The λ values, Qi values, and the ultimate ranking of the alternatives (strategies for reviving qanats) are documented in the third, fourth, and fifth columns of Table 4, respectively. As shown in Table 4, this study has seven defensive strategies, five development strategies, one competitive strategy, and four conservative strategies.

#### 3.2.1. The best strategies for reviving qanats

Following the results shown in Table 4, the most important strategies for revitalizing qanats in Razavi Khorasan Province are as follows:

Rank 1: Reforming water governance policies (WT4): The current governance policies for water resource management in the agricultural sector have prioritized modern water supply sources, resulting in limited

**Table 4**
Ranking of strategies for revitalizing qanats using the WASPAS technique.

| Strategies for reviving qanats | | λ | Qi | Rank |
|---|---|---|---|---|
| WT1 | Qanat insurance | 0.6767 | 0.2151 | 10 |
| WT2 | Determining the privacy guidelines for qanats | 0.7750 | 0.2402 | 6 |
| WT3 | The establishment of water associations | 0.7882 | 0.2264 | 8 |
| ST1 | Education, awareness, and promotion of the importance of qanats | 0.7310 | 0.2641 | 3 |
| SO1 | Structural measures to protect and water the qanat | 0.7732 | 0.1803 | 15 |
| WT4 | Reform of water governance policies | 0.7325 | 0.2850 | 1 |
| WO1 | A set of measures to control qanat water in non-agricultural seasons | 0.8123 | 0.1257 | 18 |
| SO2 | Incorporating traditional knowledge with new technologies to revive qanats | 0.6873 | 0.1920 | 13 |
| SO3 | Creating databases for qanats | 0.7424 | 0.2592 | 4 |
| WT5 | Carrying out plans for watershed management and aquifer management | 0.7297 | 0.2231 | 9 |
| WO2 | support of Magni (pitman) (a specialized profession related to qanats) | 0.7292 | 0.1892 | 14 |
| WT6 | Establishing centers to resolve disputes between shareholders | 0.7834 | 0.2054 | 11 |
| SO4 | Creating qanat tourism sites | 0.6379 | 0.1469 | 17 |
| WT7 | Improving the revival of qanats through the establishment of an independent institution | 0.7301 | 0.2775 | 2 |
| SO5 | Promoting the involvement of the private industry in investing in the restoration of qanat projects | 0.6795 | 0.2326 | 7 |
| WT8 | Allocation of low-interest credits to qanat shareholders | 0.8019 | 0.1992 | 12 |
| WO3 | Multipurpose use of qanats for optimal and profitable use of them | 0.7587 | 0.1663 | 16 |
| WO4 | Establishment of qanat research centers | 0.7509 | 0.2510 | 5 |

investment and innovation in traditional and indigenous knowledge of water supply. To harness the immense native knowledge and potential of qanats, it is essential to implement reforms in the water governance system. The analysis of water governance laws and regulations in Iran throughout history shows that during the three periods before the nationalization of water resources, the period of implementing the nationalization law, and after the enactment of the fair water distribution law, water issues persisted and intensified. The unrestrained increase in the construction of wells and water extraction from them paved the way for the destruction of qanats (traditional underground water channels). This was because the laws and regulations focused more on developing modern water resources rather than protecting and reviving indigenous and traditional water sources such as qanats (Amini, 2019). Local water governance policies prioritize community participation, respect traditional institutions, and create a balance between national and local interests. They strengthen legal structures and promote diverse stakeholder involvement. Sustainable management practices ensure environmental, social, and economic sustainability, supported by transparent data access and climate change adaptation. Cultural awareness and continuous monitoring enhance water resource management effectiveness, empowering communities to utilize resources based on indigenous knowledge and specific needs (Hashemi, 2022). In their research, Tabatabaei and Khozymehnezhad (2017) recognized the alteration of water management policies as the paramount approach for the rejuvenation of qanats. This discovery aligns with the findings of the current investigation. Sedighi Moghadam et al. (2021) emphasized the lack of proper governance of water resources in Iran. They also identified legal mechanisms as the most important solution for the sustainable management of water use from qanats (traditional water supply systems) in Yazd province, Iran. Rank 2: Improving the revival of qanats through the establishment of an independent institution (WT7): To facilitate the restoration of qanats, establishing an independent institution in collaboration with relevant stakeholders such as Khorasan Razavi Regional Water Company and the Agriculture Organization of Khorasan Razavi would be highly advantageous. To achieve this goal, the government should develop legislation and provide adequate funding to establish and support this institution. In line with the findings of the present study, the research by Ghasemi et al. (2021) also suggested delegating all matters related to qanats to a single organization or institution. This recommendation is consistent with the findings of this research. It emphasizes the need for an integrated management of qanats. In other words, both studies believe that concentrating the authorities and responsibilities related to qanats in a single governing body can be effective in improving the condition and preserving this valuable heritage. Tabatabaei and Khozymehnezhad (2017) also highlighted the importance of establishing an independent organization dedicated to the revival of qanats.

Rank 3: Education, consciousness, and advocacy of the significance of qanats (ST1): Education, consciousness, and endorsement of the significance of qanats in society are vital to conserving and rejuvenating this customary water administration system. Without the necessary cultural and intellectual infrastructure in society and the country's administrative system, efforts to revive qanats may not be successful. Furthermore, raising awareness among local communities about the importance of qanats is essential for water management and sustainable development. By educating and raising awareness about the value of qanats, local communities can become advocates for the preservation and restoration of these ancient underground water systems. Furthermore, it is essential to introduce qanats to international communities and highlight their historical and cultural value. According to a study by Mousazadeh et al. (2023), increasing public awareness about the significance of qanats can aid in preserving these underground heritage sites. Furthermore, Sadeghi Moghaddam et al. (2021) identified the awareness-raising and creating belief among farmers about the critical situation ahead and the necessity of preserving the available water resources as important factors in the revival of qanats (traditional water supply systems). The United Nations Educational, Scientific and Cultural Organization (UNESCO) has also recognized the significant importance of qanats as human heritage and their vital role in promoting sustainable management of groundwater resources in arid regions. Consequently, eleven remarkable examples of these structures in Iran have been inscribed on UNESCO's World Heritage List to acknowledge their cultural, social, political, and physical significance (Mousazadeh et al., 2023). In November 2014, an international multidisciplinary workshop on "*Re*-Use Yazd" was held in relation to water and the city. This workshop was the result of a collaboration between Iranian and French organizations, and its aim was to present innovative solutions to local authorities and the public for preserving active qanats and reviving abandoned ones. The results of this workshop showed that increasing social awareness at the local and international levels about the importance of qanats as an exceptional hydraulic system in Iran's arid regions is one of the most important strategies for the preservation and revitalization of qanats (Karimian et al. 2021).

Rank 4: Creating databases for qanats (SO3): To preserve and revive the qanat system, it is essential to create comprehensive databases regarding the characteristics, usage, and maintenance of qanats in different basins, as well as the number of beneficiaries and the amount of water withdrawal from them. Stakeholder organizations, such as the regional water and agriculture organizations, should take the lead in this regard and collaborate with local communities, experts, and researchers to collect and update the necessary information regularly. Based on the information collected, appropriate strategies, such as rehabilitation, restoration, and management plans, can be developed to revive and maintain the qanats sustainably. In this regard, Sadeghi Moghaddam et al. (2021) proposed the creation of a database on qanats as a solution to reduce the vulnerability of qanats and protect them.

Rank 5: Establishing qanat research centers (WO4): Establishing a qanat research center could play a vital role in reviving qanats. The establishment of a dedicated center with the capacity to investigate various aspects related to qanats would be highly beneficial. Such a center could focus on identifying the factors contributing to the degradation of qanats, developing effective methods for their maintenance, and exploring opportunities for qanat expansion. By conducting research and providing specialized expertise, the center could contribute to the preservation and sustainable management of qanats, ensuring their continued functionality and value for the communities that rely on them. The International Center for Qanats and Historic Hydraulic Structures is a water research institute affiliated with UNESCO. It was established with the aim of conducting studies and research in the field of qanats and historic hydraulic structures. This center is the only research institute related to qanats in Iran.

Rank 6: Determining the privacy guidelines for qanats (WT2): One of the main reasons for the destruction of qanats is lack of respect for their privacy. To prevent such destruction, it is essential to establish scientific and legal frameworks for assessing and safeguarding the privacy of qanats. The authorities must take an active role in overseeing the preservation of qanats and enforcing stringent rules that prohibit the excavation of deep and semi-deep wells. The restoration of these vital waterways depends on the participation and active involvement of the local community. Zolfagharan et al. (2018) and Fahjari and Sharifzadeh (2015) have also highlighted the importance of scientifically determining privacy guidelines for qanats and ensuring their preservation through strict monitoring, which aligns with the results of the current research. Sadeghi Moghaddam et al. (2021) identified government supervision on the drilling of wells, especially in the vicinity of qanat boundaries, as well as periodic inspections of qanats with the participation of the government and users as one of the important solutions for the revival of qanats. According to the field observations of Karimian et al. 's (2021) study, some urban developments in the buffer zone of qanats within the city have neglected the conservation requirements. This has led to the non-observance of the qanats' protected areas and has been one of the factors causing damage to these historical and valuable

structures.

Rank 7: Encouraging the private sector to invest in qanat restoration projects (SO5): To secure additional funding and expertise, encouraging private sector investment in qanat restoration projects can be beneficial. A multi-faceted approach, including financial incentives, technical assistance, and public-private partnerships is necessary to successfully encourage such investment. Moradifar and Habibabadi (2017) suggest that to address the existing challenges in managing qanats (underground water channels) and preventing them from drying up, the private sector and non-governmental organizations should place great importance on developing human resources and providing financial resources for the revival and preservation of qanats (Karki et al. 2017).

Rank 8: Establishing water associations (WT3): In the past, qanat management was typically based on a participatory approach that involved collaboration among various stakeholders. However, the breakdown of these collaborations has resulted in the deterioration of these crucial structures. The establishment of water associations has been widely recognized as a vital solution to achieve optimal agricultural water management. By consolidating the material and spiritual resources of qanat owners, these associations can be highly effective in revitalizing these structures. In this regard, Karimian et al. (2021) stated that qanats are traditional and sustainable water supply systems in arid regions of Iran that have been developed over centuries based on the concept of participatory water resource management. Therefore, to preserve and sustain these traditional systems, the revival of qanats requires more than just physical rehabilitation and maintenance efforts. It necessitates addressing social aspects and active community participation in managing these water supply systems. Reviewing management structures and promoting the concept of participatory water resource management can facilitate the sustainable revival of qanats and ensure water security in arid and semi-arid regions. Zolfagharan et al. (2018) have also stressed the importance of establishing and strengthening agricultural organizations as a potential solution for the revival of qanats, which aligns with the results of the current investigation.

Rank 9: Carrying out plans for watershed management and aquifer management (WT5): Qanats' drying up and destruction can often be attributed to a reduction in underground water levels. However, implementing effective watershed and aquifer management strategies can help to replenish these water tables and revitalize qanats. For instance, by expanding vegetation in the upper regions of the qanats, the occurrence of soil erosion can be reduced, and water infiltration into the ground can be enhanced. Additionally, the construction of earthen dams and reservoirs plays a vital role in capturing and storing water and this enables the replenishment of underground aquifers. Basiri et al. (2014) emphasize the significance of implementing comprehensive plans for watershed and aquifer management to successfully revive qanats. Such measures are essential to ensure the long-term sustainability of qanat systems. In a study conducted by Tabatabaei (2024), successful experimental methods for the conservation and revival of qanats were investigated through one case study in Yazd province. In this regard, to increase water discharge, the surface method of artificial recharge using earthen dams and the subsurface method of constructing underground dams were examined as effective and efficient approaches. Their results showed that the sustainable discharge of the Dihok Kharanagq qanat increased to 0.5 liters per second during a low-precipitation water year.

Rank 10: Qanat insurance (WT1): Qanats are susceptible to various hazards such as floods and earthquakes. These structures are typically owned by small-scale farmers who may have limited financial resources to rebuild in the event of damage. To safeguard and revitalize this indigenous knowledge, offering insurance coverage for qanats can be an effective solution. As per the study carried out by Mostafaeipour (2010), the absence of insurance coverage for qanats caused a dearth of renovation, eventually leading to their destruction.

Rank 11: Establishing centers to resolve disputes between shareholders (WT6): The destruction of qanats is often caused by disputes among their shareholders. These qanats are typically quite old and legal ownership documents may be lacking or unclear, leading to disagreements among stakeholders. To address this issue, it is recommended that a center be established to facilitate the resolution of such disputes. This could be achieved through the implementation of laws and regulations and creation of an independent organization staffed by experienced experts in the field of qanat dispute resolution. Based on the findings of Ghasemi et al. (2021), setting up centers to handle disputes among stakeholders is a crucial strategy to revitalize the qanats. This suggestion corresponds with the findings of the present research.

Rank 12: Allocating low-interest credits to qanat shareholders (WT8): The shortage of government credits and the absence of appropriate planning to grant facilities to the shareholders of the qanats are among the factors contributing to the deterioration of these structures. To revive and preserve qanats, it is necessary to implement proper planning to provide low-interest loans to their shareholders. In this regard, Azizi Khalkheili et al. (2016) considers improving the government's credit system to address financial problems and lack of capital for farmers (low-interest loans, crop insurance, production subsidies, etc.) as a solution to reduce the vulnerability of qanats. With the support of the Center for Sustainable Development and Environment (CENESTA), a community empowerment project was carried out in the Takab Rural District, in Kerman. This project was able to not only increase the empowerment of women through the establishment of a cooperative, but also help in the revitalization of qanats in this region (Karimian et al., 2021).

Rank 13: Incorporating traditional knowledge with new technologies to revive qanats (SO2): The integration of traditional knowledge with modern developments represents a promising strategy to enhance the effectiveness and sustainability of various practices, including the construction and restoration of qanats. This approach involves combining the insights and skills of traditional experts with the latest technological advancements to create more efficient and durable qanats that can withstand the test of time. In this regard, the researchers Sadeghi Moghaddam et al. (2021) recommended using modern technologies and new facilities in the construction and rehabilitation of qanats as a suitable solution to reduce the vulnerability of qanats and protect them. They suggested that by employing up-to-date technologies in the construction and restoration of qanats, potential damage to this valuable heritage can be prevented and their sustainability can be ensured. They also suggested utilizing extension services in order to preserve indigenous knowledge as well as integrating it with new issues and methods.

Rank 14: Supporting Magni (pitman) (a specialized profession related to qanats) (WO2): The qanats are being destroyed due to the decline of the Magni profession. As the number of Magnis decreases, maintaining and repairing the qanats becomes increasingly complex, eventually leading to their deterioration. The challenging nature of this job, combined with the lack of insurance support, has caused many Magnis to suffer financial hardships. To address this problem, it is crucial to establish support and insurance platforms for Magnis. Such initiatives can encourage more people to pursue this profession, increasing the number of skilled Magnis. Additionally, training courses should be organized in this field to maintain Magni's specialized profession and ensure that the qanats are appropriately maintained and repaired. In a study, Ghasemi et al. (2021) identified the advanced age of qanat workers (Magni) and their physical inability as one of the main reasons for the deterioration of qanats. To revive these valuable heritage structures, they proposed training a new generation of Magnis who are familiar with the experiences of their predecessors and also knowledgeable about modern issues and challenges. This suggestion aligns with the findings of the present study. In the study by Moradifar and Habibabadi (2017), it is suggested that to address the challenges of managing qanats and preventing their drying up, it is essential for the government, local authorities, the private sector, and non-governmental organizations to place great importance on developing specialized human resources such as pitmans (Magni) (a specialized profession related to qanat) and enhancing their professional status. Additionally, it

proposes strengthening institutions, capacity building, developing organizational structures, and establishing associations and educational classes to support pitmans (Karki et al. 2017). The Moradifar and Habibabadi (2017) mention that in some villages of East Biosphere of Chaharmahal and Bakhtiari Province, officials encourage the youth to participate in the maintenance and cleaning of qanats by hiring experienced pitmans and paying money to the youth. The important point is that the youth of these villages show a greater interest in participating in the management of qanats (Karki et al. 2017).

Rank 15: Structural measures to protect and water the qanat (SO1): Structural measures such as periodic dredging, collar-making, culling, side trimming, floor breaking, etc. can effectively increase the water supply of the qanat and protect it. Therefore, it is recommended to implement such measures in the future. In a study conducted by Tabatabaei (2024), successful experimental approaches for the preservation and revitalization of qanats were investigated through a case study in Yazd province. In this regard, in order to increase the water flow, protection measures in three parts such as resilience against external factors, improvement to prevent disruption in the internal functioning of the aqueduct, and finally the construction of a flood diversion dam were investigated as effective and efficient approaches. The findings of this research indicated that with the implementation of these measures, the dilapidated Khamsian qanat, with a discharge rate of 0.5 liters per second, was brought back into operation.

Rank 16: Multipurpose use of the qanat for optimal and profitable use of the qanat (WO3): To fully leverage the qanat's potential for profitability, a multi-purpose approach can be adopted that utilizes it as a versatile water source for various applications such as fish farming, industrial processes, hydroelectric power generation, potable water supply, and tourism. This strategy has the potential to boost the qanat's efficiency while generating economic, social, and environmental benefits. By adopting this approach, we can maximize the value of the qanat while promoting sustainable development in the region. Several studies have suggested the multiple uses of qanats for their optimal and profitable utilization. For instance, Sadeghi Moghaddam et al. (2021) recommended using qanat water for drinking purposes during non-agricultural seasons. Karimian et al. (2021) introduced fish farming and tourism use of qanats as sources of income. These studies have considered diversifying the income sources of qanat users as a method to preserve this valuable heritage. In other words, generating diverse incomes through various applications of qanats can provide the necessary incentive for their maintenance and preservation.

Rank 17: Creating qanat tourism sites (SO4): Creating tourist sites for qanats is an excellent opportunity to develop the tourism industry and protect this historical heritage. Tourism sites can help introduce and advertise these historical attractions by providing comprehensive and accurate information about qanats. In addition, tourist sites can help tourists to know more precisely when to visit, how to access, and what activities to do around the qanats. Creating tourism sites and holding tourism tours for qanats can help to protect this historical heritage and, at the same time, contribute to the sustainable development of the tourism industry in rural areas (Miani et al., 2023). The creation of a museum to display the qanat irrigation system has attracted thousands of Chinese and international tourists to the qanats in Turpan. This operation has led to the preservation of these qanats and the development of strategies for their continuous use (Abudu et al., 2014). Creating conditions for tourists to visit the Zarch Qanat in Yazd was one of the activities aimed at preserving this qanat and improving its water quality. This qanat was eventually inscribed on the UNESCO World Heritage List in 2016 (Karimian et al., 2021). Moayedfar and Fatemi (2021) as well as Mousazadeh et al. (2023) have highlighted the reciprocal relationship between the restoration of qanats and tourism in their studies, emphasizing the vital role of tourist sites in this field.

Rank 18: A set of measures to control qanat water in non-agricultural seasons (WO1): During non-agricultural seasons in Razavi Khorasan province, water from the qanat is often wasted due to prevailing climatic conditions. To address this issue, constructing underground dams and chain pools can provide a practical solution to conserve water. These structures can effectively capture and store water from the qanat, which can later be used for irrigation and other purposes as needed. Overall, building underground dams and chain pools can help mitigate water scarcity issues during non-agricultural seasons in Razavi Khorasan province. Sadeghi Moghaddam et al. (2021) showed that combining underground dam technology with qanats can prevent the loss of low groundwater flows from shallow alluvial aquifers and direct them into the qanats. By storing the qanat water in the alluvium behind the dam, loss of groundwater flows during the rainy season can be prevented, and the groundwater aquifer feeding the qanat can be quantitatively improved.

Overall, if the formulated strategies are implemented effectively and the sequence of their implementation is observed by the policymakers, there is a good chance that the qanats can be revived as a sustainable local water source.

### 3.3. Research limitations

In spite of the valuable perspectives and contributions of this research, it is crucial to recognize its constraints. Firstly, the focus on the province of Razavi Khorasan in Iran restricts the generalizability of the findings to other regions with different geographical, cultural, and socio-economic contexts. The unique characteristics of this province may influence the outcomes and applicability of the proposed qanat restoration strategies. Therefore, caution should be exercised when extrapolating the results to other regions without considering their specific conditions. Additionally, the study's reliance on a specific set of methodologies, such as the SWOT analysis, BWM, and WASPAS, introduces potential biases and limitations inherent to these techniques. Different methodological approaches might yield different perspectives and outcomes. Furthermore, the study's scope might not encompass all potential factors influencing qanat restoration, as complex systems such as water management involve numerous interrelated variables that are challenging to capture comprehensively. Finally, the research time frame and available resources might have imposed limitations on data collection and analysis, potentially impacting the depth and breadth of the study's findings.

## 4. Conclusion

The present study aimed to identify the most effective strategies to revive qanats, a vital traditional water supply system, in the arid and semi-arid region of Razavi Khorasan province, Iran. By integrating the SWOT analysis, BWM, and WASPAS, the research systematically evaluated the internal and external factors influencing qanat restoration and prioritized the optimal strategies. The experts highlighted maintaining aquifer balance, lack of funds for maintenance, international convention support, and drought as the most significant internal and external factors influencing qanat restoration. The factors highlighted the multifaceted nature of reviving qanat systems, where maintaining a delicate balance between natural resources, infrastructure, governance, and global cooperation is crucial. The WASPAS technique was then utilized to rank 18 practical strategies for qanat revival. The findings of this research indicate that the top priority for the revival of aqueducts is to reform water governance policies. Following this, the second most important strategy is the establishment of an independent institution for aqueduct revival. Accordingly, policymakers should initially concentrate on macro and institutional strategies related to the restoration of aqueducts. Therefore, in order to exploit this valuable source of indigenous knowledge and revive aqueducts, it is necessary to undertake water governance systems and institutional reforms prior to any action. This is because current governmental and institutional policies pertaining to managing water resources in the agricultural sector have been focused on modern water supply sources, thereby limiting investment and innovation in traditional and indigenous knowledge of water

supply.

Upon successful implementation of these strategies at the macro level, this study proposes that policymakers should shift their attention towards other aspects associated with the revival of aqueducts, such as education and research in the field of aqueducts, enhancement of aqueduct infrastructure, and, ultimately, establishment of supportive policies for qanat custodians.

In this regard, international organizations such as FAO and UNESCO can both play crucial roles in the revival of aqueducts. FAO's contribution lies in providing technical expertise for aqueduct design and construction, capacity building for water management professionals, promoting sustainable water management practices, and facilitating financing options.

Furthermore, UNESCO can play a vital role in safeguarding and restoring aqueducts by officially designating them as world heritage sites and conducting educational and informational campaigns to raise public awareness. By combining their expertise and resources, FAO and UNESCO can work together to restore and preserve aqueducts, safeguard their cultural values, and ensure sustainable water management practices for future generations.

Based on the results, by combining SWOT analysis, BWM, and WASPAS, the research provides a robust and holistic framework for decision-makers to address the multifaceted challenges associated with the restoration of this traditional water supply system. The theoretical implications of this study include the application of a novel integrated methodology to the context of indigenous water management, contributing to the growing body of literature on sustainable water resource solutions. From a practical standpoint, the prioritized strategies offer a roadmap for policymakers, regional water authorities, and local communities to effectively revive and integrate qanats into the contemporary water management landscape, ensuring the long-term sustainability of agricultural practices and water security in arid and semi-arid regions.

### *4.1. Water governance policy*

Reforms in water governance policies can significantly contribute to reducing the consequences of drought and aiding in the revival of traditional water resources such as qanats. These reforms include the development of comprehensive management approaches such as utilizing modern technologies for water-efficient agriculture, implementing educational programs to increase awareness of the importance of preserving water resources, reforming water pricing structures to incentivize sustainable consumption, as well as providing financial and policy support for the maintenance and rehabilitation of traditional water sources. These policies also emphasize integrated water resource management and encourage local community participation, providing a foundation for enhancing community resilience to climate change. Additionally, it is crucial to develop groundwater management plans that include extraction limits and recharge strategies, shift subsidy patterns to encourage the use of water-efficient technologies, modernize the legal framework for water allocation to ensure equitable distribution, create preparedness and response plans for drought conditions, integrate water considerations into land use planning, invest in ecosystem restoration and protection to enhance water conservation, treatment, and reuse, and implement public awareness and education initiatives to promote water conservation.

The development and implementation of local water governance policies are operationalized based on the following principles:

- Local Community Participation: Providing platforms to strengthen participation and decision-making of local communities in water resource management. This includes empowering and enhancing local awareness and knowledge of ecosystems and water systems.
- Recognition and Respect for Non-Formal Institutions: Recognizing and enhancing the role of non-formal and traditional institutions in water resource management and assessing local approaches to conserving water resources.
- Balancing National and Local Interests: Striking an appropriate balance between national and local interests to ensure both national water security and local needs are met.
- Strengthening Legal and Executive Structures: Establishing and strengthening legal structures that ensure the implementation of participatory decisions by local communities.
- Diversifying Participation: Inviting all local stakeholders including farmers, industries, non-governmental organizations, and government agencies to participate in decision-making.
- Sustainable Management: Adopting management approaches that guarantee environmental, social, and economic sustainability simultaneously.
- Transparent Data and Information: Promoting free access to water-related information and effective use of scientific data in decision-making.
- Climate Change Adaptation: Aligning policies with the needs arising from climate change and weather fluctuations.
- Cultural Awareness: Promoting and deepening public understanding of the importance of water resource sustainability and changing consumption patterns.
- Continuous Monitoring and Evaluation: Implementing dynamic policies with continuous monitoring and evaluation of various aspects of water resource management.

These policies, when implemented together, contribute to increasing efficiency and independence in local water management, allowing communities to utilize and manage their water resources based on indigenous knowledge and specific needs. Local water governance policies prioritize community participation, respect for traditional institutions, and balance between national and local interests. They strengthen legal structures and promote diverse stakeholder involvement. Sustainable management practices ensure environmental, social, and economic sustainability, supported by transparent data access and climate change adaptation. Cultural awareness and continuous monitoring enhance water resource management effectiveness, empowering communities to utilize resources based on indigenous knowledge and specific needs.

## 5. Suggestions for future studies

In order to progress the domain of multi-criteria decision-making (MCDM) in the context of qanat restoration and other correlated research fields, forthcoming investigations ought to investigate substitute techniques that widen the range of analysis and offer a more comprehensive outlook. One such method worth investigating is the Decision Evaluation and Experimentation Laboratory (DEMATEL) technique. DEMATEL is an experimental decision-making and evaluation method that can be used to explore the interrelationships among sub-factors or strategies. By applying DEMATEL, researchers can gain insights into the complex interdependencies within the decision-making framework, thereby enhancing the understanding of the research problem.

Furthermore, upcoming studies should take into account the integration of emerging MCDM techniques, such as the ordinal preference strategy (OPA). OPA offers a novel approach to decision-making by considering the ordinal nature of preference statements and allowing decision-makers to express their preferences in a more intuitive and flexible manner. By integrating OPA or similar innovative methods into the research process, the effectiveness of the decision-making process can be improved, enabling more accurate and reliable outcomes.

Comparative studies that assess the results obtained from different MCDM methods would also contribute to a more comprehensive understanding of the research problem. By evaluating and contrasting the outcomes derived from various decision-making techniques, researchers

can identify the strengths, weaknesses, and limitations of each method. This comparative analysis can provide valuable insights into the suitability and applicability of different MCDM methods in the specific context of qanat restoration and guide future researchers in selecting the most appropriate approach for their studies.

In summary, future research in the field of MCDM should explore alternative methods such as DEMATEL and consider the incorporation of emerging approaches such as OPA. Comparative studies that evaluate different decision-making methods would further enrich the understanding of the research problem and contribute to the development of more effective strategies for qanat restoration and related endeavors.

## Declarations

**Ethical Approval:** None.

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**Research involving Human Participants and/or Animals:** None.

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## CRediT authorship contribution statement

**Sasan Esfandiari Bahraseman:** Methodology, Formal analysis, Conceptualization. **Ali Firoozzare:** Writing – review & editing, Validation, Supervision. **Can Zhang:** Writing – review & editing. **Nazanin Yousefian:** Writing – review & editing. **Rytis Skominas:** Writing – review & editing. **Reza Barati:** Writing – review & editing. **Hossein Azadi:** Writing – review & editing, Validation.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

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