



Research Article

Priority Ranking of Qanat Rehabilitation Using Analytic Hierarchy Process (Case Study: Southern Khorasan)

Hassanpour, M.^{a,*}, Khozaymehnezhad, H.^a, Khashei-Siuki, A.^a

^a Department of Water Engineering, Birjand University, Birjand, Iran

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Abstract


Every year, significant amounts of funding from government allocations are allocated towards the restoration and conservation of qanats. However, due to insufficient information, some qanats have undergone reconstruction and maintenance despite not being a priority for restoration. Additionally, implementing modern and technical operations in qanat reconstruction requires thorough examination, studies, and design. Through comprehensive identification and supplementary studies, all aspects of the qanats can be assessed from upstream to downstream, and after designing, the initiative for fundamental qanat reconstruction can be taken. Prioritizing qanat reconstruction greatly facilitates this process. This research focuses on the revival and restoration of qanats from both managerial and technical perspectives. Using the Analytical Hierarchy Process (AHP) method and Expert Choice software, 10 qanats from the plain group and 10 qanats from the mountainous group were prioritized in each perspective. The indicators used for prioritizing qanats included discharge, length, depth, chemical quality, rainfall, distance from waterways, population, and cultivated area. This research introduces a new scientific method for prioritizing the restoration and rehabilitation of qanats. Additionally, the method employed in this research selects qanats as a priority for rehabilitation and restoration, which can achieve desired irrigation with the allocated cost. In this study, the Boshrouye qanat in the plain group was prioritized for restoration and rehabilitation from both managerial and technical points of view, with weights of 0.17 and 0.163, respectively. Also, the Darmian qanat was prioritized for restoration and rehabilitation in the mountainous group from both managerial and technical perspectives, with weights of 0.265 and 0.219, respectively.

Homepage: www.wss.torbath.ac.ir

*Corresponding Author:

Hassanpour Mojtaba

Email: mbohlool69@yahoo.com

 ORCID: 0000-0002-6871-2771

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1- Introduction

Qanats have long been recognized as one of the most significant human achievements in acquiring water in desert regions. Throughout history, the preservation and maintenance of qanats have been a focal point of human attention. Various tools have been utilized to excavate and protect them ([Mahdi Zadeh Ardakani, 2014](#)). The art of qanat construction is a remarkable technique and a thoughtful invention attributed to Iran ([Malki and Khorsandi, 2005](#)). By utilizing a slope lower than the natural surface of the earth, qanats allow water to flow from higher areas or rivers to lower areas solely through the force of gravity, without the need for mechanical or thermal energy ([Haeri, 2016](#)). Fuzzy multi-criteria decision-making has gained significant attention in the field of decision-making science. The application of fuzzy logic has given rise to various methods for addressing multi-criteria decision-making problems ([Amiri, 2010](#); [Cavallaro, 2010](#)). Raju and colleagues (2004) utilized five decision-making methods, including PROMETHEE-2, ELECTRE III, EXPROM-2, ELECTRE-4, and adaptive programming (CP), to prioritize water resources projects in Huesca, Spain. [Brahimi et al. \(2004\)](#) presented their experiences in the study of qanat reconstruction and repair. They provided information on the various stages of qanat analysis, the description of required services, upstream conditions of the qanat, privacy concerns, and the necessary parameters for study and evaluation. This comprehensive approach ultimately led to the identification of qanats, mapping the existing conditions, and addressing technical issues. In a separate study, [Noshadi and Farhadi \(2013\)](#) measured and investigated various parameters, such as deterioration, sedimentation, erosion, collapse, and floor damage, in 34 qanats located in the arid and water-scarce province of Yazd. These qanats are scattered across different parts of Yazd province and the cities of Abarkoh (3 streams), Bafiq (2 streams), Taft (4 streams), Khatam (3 streams), Sadouq (10 streams), Tabas (2 streams), Mehriz (7 fields), Maybod (2 fields), and Yazd (1 field). The initial studies involved meteorology, hydrology, physiography, hydrogeology, geology, and water requirements in the upstream basins of these qanats.

Subsequently, the longitudinal profiles of the qanats were drawn, and their slopes were

calculated. Watershed operations necessary upstream of these qanats were also identified and designed. Based on the study results, field visits to the basin and inside the qanat tunnels were conducted to determine the required operations for qanat improvement and renovation. The findings indicate that demolition and dredging operations are the most common, accounting for 88.24% and 79.41%, respectively. Additionally, chipping, culling, and floor breaking operations are frequently employed for renovation and improvement, with percentages of 76.47% and 59.59%, respectively, accounting for 70% and 58.82%.

Hierarchical analysis, in the context of data mining, refers to the process of organizing and analyzing data at different levels of granularity or abstraction, allowing for the exploration of relationships and patterns across multiple hierarchical levels ([Van et al., 2019](#)).

Ghahrani et al. (2014) conducted a study titled "Determining the Appropriate Places to Use Excess Water from qanats to Feed the Aquifer Using the AHP: A Case Study of Razavi Khorasan Province." The researchers combined maps and applied the AHP method to assign weights to different zones. The final map was classified into three classes. The results revealed that 0.36% of the qanats and 0.01% of the springs had the potential to replenish the aquifer. In another study, [Bahramlou and Abbasi \(2010\)](#) investigated the qanat exploitation system of Hamedan province. They found that the drying up of qanats, resulting from inadequate management and timely maintenance, was one of the main causes for the evacuation of villages. [Zarchesham et al. \(2013\)](#) explored the integration of GIS and a decision support system to identify suitable areas for flood spreading operations. They evaluated various scenarios using weighted maps and assessed the average desirability of sub-areas to determine the best locations for flood spreading. [Nouri et al. \(2009\)](#) conducted a study on the application of multi-criteria decision-making methods in water resources management. The research demonstrated that these methods are suitable for complex decision-making processes and have been widely adopted in the field. [Zare et al. \(2012\)](#) explored the feasibility of artificial feeding projects using spatial multi-criteria decision-making methods. The study assessed various criteria and decision-making tools to determine the viability of such

projects. [Ramezani Mehraban et al. \(2013\)](#) employed fuzzy logic and the TOPSIS method to select optimal locations for artificial feeding areas in Abkhavan. The combination of multi-criteria decision-making methods, GIS analysis, and fuzzy logic provided efficient tools for determining suitable locations based on expert judgments and linguistic preferences. [Shanbadian and Mogholi \(2023\)](#) They investigated the aqueducts of Siraf city and chose the best aqueduct for investment and restoration. In this regard, by using various parameters such as the length of the aqueduct, the diameter of the ring of the well of the aqueduct, the distance from the city, the safety and the amount of water flow, checking these parameters in the Fuzzy ANP method, which in the Super Decision software by giving weight to them and preparing maps Relatedly, it was analyzed using the geographic information system and according to all the parameters and weights assigned by each one, the best aqueduct was selected for investment. The results indicate that the Dubai criterion with rank 1 has the highest priority for revitalization and reconstruction. Rainfall criteria with rank 2, population with rank 3, cultivated area with rank 4, chemical quality of water with rank 5, distance from waterway with rank 6, length of aqueduct with rank 7 and depth of aqueduct with rank 8 are in the next priorities. [Mohammadi et al. \(2012\)](#) analyzed the sensitivity of ranking dam construction projects in Chaharmahal and Bakhtiari provinces using various multi-criteria decision-making methods, including ELECTRE III, Minimax, weighted distances, least squares, and AHP. The results indicated that the ELECTRE III method was the most appropriate due to its robustness and lower sensitivity to changes in ranking.

In the conducted researches, they have generally referred to the study discussions about the upstream of the qanats, the identification of qanats, etc. It is also mentioned about the executive operations of renovation and improvement without mentioning preliminary studies. In this research, using hierarchical analysis, for the first time, the characteristics of each aqueduct have been used to prioritize the renovation of the aqueducts so that the next steps in the field of renovation will be more effective.

The construction of qanats dates back to the past, and currently, these structures primarily require maintenance and restoration. With proper

methods of operation and maintenance, qanats can have a longer lifespan compared to other water facilities. Water extraction from qanats is achieved through gravity, without the need for energy or mechanical devices, aligning with local knowledge and practices. The underground water extraction system using qanats has been preserved in its traditional form for many years, with minimal changes. Despite technological advancements, the fundamental reconstruction of qanats has not undergone significant alterations. However, considerable funds are allocated each year from government budgets for the restoration and rehabilitation of qanats. Unfortunately, due to insufficient information, restoration efforts have sometimes focused on qanats that were not prioritized.

Implementing new technical operations in qanat reconstruction necessitates thorough investigation, studies, and design considerations. By conducting comprehensive surveys and supplementary studies, all aspects of the qanat, from its upstream to downstream sections, can be examined. Subsequently, after the design phase, the actual reconstruction of the qanat can commence. Prioritizing the reconstruction of qanats is crucial in ensuring efficient resource allocation and effective restoration efforts.

However, despite the repeated visits by aqueduct owners, their readiness to participate, and the absence of any action taken to restore the aqueducts, there is a need to prioritize the allocation of funds for their restoration (as stated by the Water and Soil division of Agricultural Jihad Organization, South Khorasan). Each year, substantial amounts of government funding are dedicated to the restoration and reconstruction of aqueducts. However, the lack of specific criteria for prioritizing aqueduct restoration, coupled with a dearth of scientific and expert discussions on the subject, has resulted in the potential misallocation of these funds. It is crucial to seek an appropriate solution to prevent the wastage of allocated funds and ensure their efficient utilization.

2- Material and methods

2-1- Qanats of the studied area

According to the water resources statistics of 2010, South Khorasan Province has 6006 aqueducts with a total water discharge of 38.243 million cubic meters per year. In 2011, an agreement on the identification of unregistered

qanats was concluded, and about 1000 other qanats are expected to be added to these statistics and reach 7000 qanats ([Basij Sazandagi Organization, 2011](#)).

In this study, the prioritization of qanats in South Khorasan is discussed from two perspectives listed in following.



Figure 1. South Khorasan location

2-2- Managerial perspective

The managerial perspective suggests that by managing the available financial resources, the water supply resulting from the restoration of the qanats can be increased. In this perspective, both the characteristics of the qanats themselves and the surrounding factors such as population and cultivated area are taken into account. According to this viewpoint and expert opinions, factors such as higher flow rate, larger population, better water quality, higher precipitation, and larger cultivated area are considered important. Regarding the length and depth, it is believed that they have less significance as the qanats can be revived at a lower cost. The importance of a qanat is determined by its distance from the main waterway, as the closer the qanat is to the waterway, the less significant it becomes. This is because heavy rainfall along the waterway can lead to qanat destruction and increased sediment deposition.

2-3- Technical perspective

The technical perspective focuses solely on the technical characteristics of the qanats. In this viewpoint, the prioritization of qanat restoration is based on their sustainability and reliability as a water source. According to this perspective, similar to the managerial viewpoint, higher flow rate, better water quality, and increased precipitation carry higher importance. Regarding the length and depth, it is believed that qanats with greater length and depth are more sustainable and reliable. In

terms of distance from the main waterway, if a qanat is located along the waterway, considering that the waterway usually follows the contour line, the flow will be directed towards the feeding area and the qanat route. Protective measures can be taken to prevent destruction and sediment deposition.

In this study, to conduct a more detailed and realistic examination, the qanats were divided into two groups: plain qanats and mountainous qanats.

2-4- Plain qanats

Plain qanats are located in flat areas and have a lower elevation compared to mountainous qanats. They primarily rely on surface water sources such as rivers and groundwater for their water supply. These qanats play a crucial role in providing irrigation water for agricultural activities and supporting the growth of crops throughout the year. The availability of water in plain qanats remains more stable and consistent compared to mountainous qanats ([Basij Sazandegi Organization, 2011](#)). The qanats studied in this research are of the permanent type.

2-5- Mountainous qanats

Mountainous qanats are located in mountainous areas and have a higher elevation compared to plain qanats. They primarily rely on rainfall and snowmelt for their water supply and may have steep slopes and higher runoff. These qanats are more susceptible to fluctuations in water availability, especially during the spring season

when snowmelt and rainfall contribute to increased water flow. However, during the summer season, the water supply in mountainous qanats tends to decrease (Basij Sazandegi Organization, 2011).

2-6- Analytical Hierarchy Process (AHP)

Multiple Attribute Decision-Making methods have gained prominence in decision-making processes over the past few years. Among these methods, the Analytical Hierarchy Process (AHP) has been widely utilized in the field of management science. The AHP, introduced by Thomas L. Saaty, an original Iraqi mathematician, in the 1970s, has surpassed other methods in terms of its application. The AHP is a renowned technique for multi-objective decision-making and

reflects the natural behavior and thought process of humans. By breaking down complex problems into simpler forms and considering their interactions, the AHP facilitates problem-solving. Fig. (2) depicts the hierarchy diagram used for prioritizing the revitalization and restoration of significant qanats in Southern Khorasan. (Asgharpour, 2013; Saaty, 1990; Schenkerman, 1994). In the figure below, from top to bottom, the first goal is to prioritize the reconstruction of qanats in the current research. Then the desired criteria include discharge, length, depth, water quality, cultivated area, population, rainfall and the distance of the qanat from the river. And at the lowest level of the chart are the research options, which include the important qanats of South Khorasan.

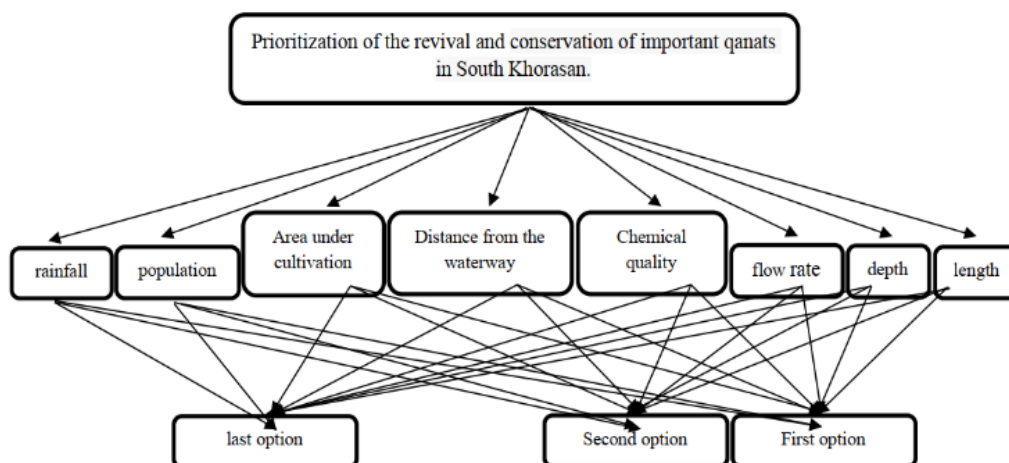


Figure. 2. Hierarchy diagram for prioritizing the restoration of important qanats in South Khorasan

In this research, the important qanats of South Khorasan, which were considered important based on their flow rate, were examined and prioritized for restoration. The restoration and preservation of these qanats were categorized into two perspectives: managerial and technical. In each perspective, 10 plain qanats and 10 mountainous qanats were prioritized. The reason for selecting 10 qanats is that exceeding this number would increase the computational workload, making the method impractical, and it would also reduce the accuracy of the work due to the high number of qanats. This method is most commonly used for prioritizing qanats within a specific region.

In this research, for a more detailed examination, the qanats were divided into two groups: plain qanats and mountainous qanats. The prioritization diagram for the restoration of the

qanats is shown in Fig. 3.

In this study, a total of 20 permanent qanats with higher flow rates in South Khorasan province were examined for prioritizing restoration and preservation. Most of these qanats are located in the eastern and northern parts of South Khorasan. As mentioned earlier, two perspectives, namely managerial and technical, were considered for the restoration and preservation. In each perspective, 10 qanats were prioritized in the plain group and 10 qanats in the mountainous group (Tables 1 and 2). The reason for selecting 10 qanats is that exceeding this number would increase the computational workload, resulting in a decrease in work accuracy due to the high number of qanats. This method is most commonly used for prioritizing qanats within a specific region.

2-7- Parameters Influencing Qanats Prioritization

It should be noted that no previous research has been conducted in this area. Based on expert opinions, the following parameters have been

selected:

Precipitation, Population, Flow rate, Surface area, Cultivated land, Length, Depth, Distance from waterway route, Water quality

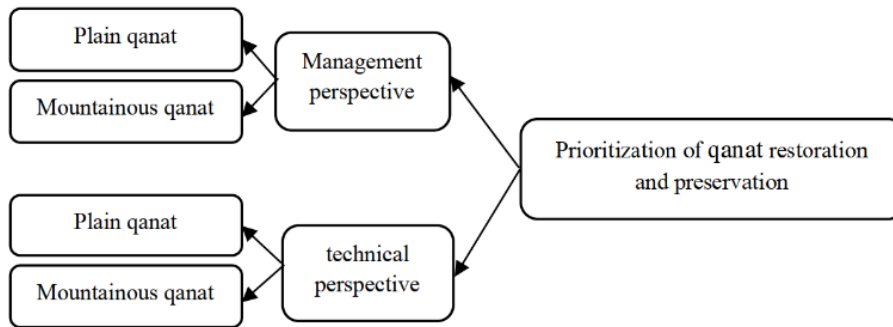


Figure. 3. Prioritization diagram for the restoration and preservation of qanats in South Khorasan.

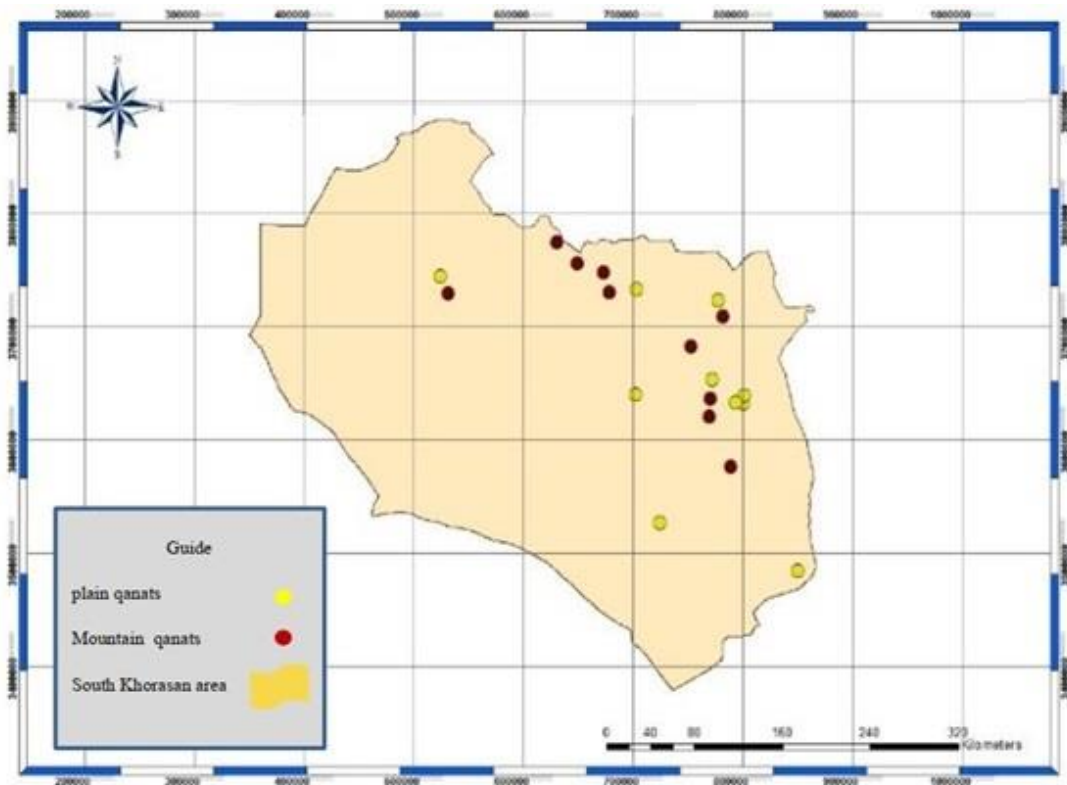


Figure. 4. The location of Maderchah of the important plain and mountain aqueducts in need of reconstruction in South Khorasan

Table 1. Specifications of Plain qanats

Row	Name of Qanat-city	Rainfall (mm)	Population (person)	flow rate(Lit/Min)	Cultivated area (hectares)	length (m)	depth (m)	Distance from the waterway (m)	Chemical quality (μ mhbo/cm)
1	Boshrouye- Boshrouye	120	13778	45	50	1200	30	On the way	780
2	Hajiabad-Birjand	150	1821	40	80	6400	50	600	7070
3	Hajiabad-Nehbandan	150	32	40	40	1500	15	On the way	6710
4	Mohammadabad-Darmian	150	760	35	120	6500	40	3000	2780
5	Sofla Tabasin-Nehbandan	70	925	34	35	7000	40	400	6220
6	Aliabad-Darmian	160	436	33	160	5300	90	3000	4880
7	Nougab- Darmian	170	3390	32	50	4450	55	On the way	6810
8	Abu al-Khairi-Qain	260	38	30	30	3000	40	1000	1420
9	Ahmedabad- Darmian	150	430	29	140	3000	38	1700	2010
10	Haji Abad - Qain	250	650	14	30	2000	30	400	4700

Table 2. Specifications of mountainous qanats

N.O.	Name of Qanat-city	Rainfall (mm)	Population (person)	flow rate(Lit/Min)	Cultivated area (hectares)	length (m)	depth (m)	Distance from the waterway (m)	Chemical quality (μ mhbo/cm)
1	Ersk-Basroiye	130	3662	34	35	400	7.5	2000	2420
2	Darmian - Darmian	220	4839	32	200	1000	55	on the way	1020
3	Ardakoul-Qain	175	445	27	80	100	5	1200	400
4	Khan- Darmian	180	446	16	57	284	8	on the way	1110
5	Apo-Sarayan	275	2663	15	10	250	10	on the way	285
6	Baraz-Qain	250	728	14.5	60	300	12	600	390
7	Kangan-Sarbisheh	200	160	14	10	574	16	on the way	630
8	Grimonj-Qain	200	1235	13	60	500	17	350	1460
9	Qanbar-Sarbisheh	170	86	12	15	500	10	600	5100
10	Sheshtok-Ferdows	220	94	10	30	800	17	on the way	820

These indicators were scored by 30 expert qanat specialists, and the geometric mean of the scores obtained was calculated. The calculated average was used as the main score in the matrix, and the calculations of the indicators were determined based on statistical relationships. Additionally, to determine the accuracy of the calculations, the level of inconsistency rate, the value of inconsistency index, and the random index were determined, where this value should be less than 0.1 in the calculations. In this study, the Expert Choice software was used for analysis/prioritization of qanat restoration and preservation using the Analytic Hierarchy Process (AHP).

3- Results and Discussion

3-1- Weight determination

Based on Table 3, the prioritization of flow rate from a managerial perspective is determined based on expert opinions. The subsequent priorities include the characteristics of cultivated land, population, rainfall, water quality, depth, distance from the waterway route, and length. According to Table 4, in the technical perspective, the priorities are flow rate, precipitation, water quality, depth, distance from the waterway, and length, respectively. Tables 3 and 4 present the relative weights of these criteria from the managerial and technical perspectives. The inconsistency rate of the pairwise comparison of these criteria was 0.05 and 0.03, respectively, indicating an acceptable level of accuracy in this pairwise comparison

(Saaty, 1990)

3-2- Binary comparison of options based on criteria

After determining the weights of each criterion, in the next step, the options need to be pairwise compared based on each criterion. To determine the priorities, the concept of normalization, which was explained in the previous step, is used. After normalization, the weight of each option is obtained based on the respective criterion. Tables 5 and 6 indicate the relative weights of the options regarding the prioritization criteria for the restoration and conservation of plain qanats from a managerial and technical perspective. Additionally, in Tables 7 and 8, the relative weights of the options are presented in terms of the prioritization criteria for the restoration and conservation of mountainous qanats from a managerial and technical viewpoint.

3-3- The final scores and rankings of the qanats are determined from both managerial and technical perspectives

Ultimately, the qanats were prioritized from both managerial and technical perspectives, and their final scores and rankings were determined. (Figure 5 and 6, Tables 9 and 10).

3-4- Conclusions and Future Direction

Qanats contribute to employment generation in the region and also help promote economic growth and sustainable development. Therefore, it is necessary to pay closer attention to their restoration and conservation. The most significant challenge currently in the discussion of qanat restoration and conservation is that qanats are being prioritized for restoration and conservation even though they are not truly in need, leading to a waste of national capital. Currently, according to experts, there is no scientific and definitive solution for prioritizing qanats, and prioritization is done based on limited criteria.

Table 3. Relative Preference Matrix of Criteria and Weight of Each Criterion from the Managerial Perspective

Criteria	length	depth	flow rate	water quality	distance from waterway	rainfall	Area under cultivation	population	special vector (normalized weight)
length	1	1/4	1/9	1/6	1/3	1/5	1/7	1/8	0.019
depth	4	1	1/8	1/4	3	1/4	1/6	1/7	0.041
flow rate	9	8	1	5	7	6	2	3	0.341
water quality	6	4	1/5	1	5	1/2	1/4	1/3	0.078
distance from waterway	3	1/4	1/7	1/5	1	1/5	1/8	1/8	0.027
rainfall	5	4	1/6	2	5	1	1/3	1/2	0.100
Area under cultivation	7	6	1/2	4	8	3	1	2	0.228
population	8	7	1/3	3	8	2	1/2	1	0.166

Table 4. Relative Preference Matrix of Criteria and Weight of Each Criterion from the Technical Perspective

Criteria	length	depth	flow rate	water quality	distance from waterway	rainfall	Area under cultivation	special vector (normalized weight)
length	1	1/3	1/7	1/4	1/2	1/5	0.039	
depth	3	1	1/5	1/2	2	1/3	0.091	
flow rate	7	5	1	4	6	3	0.448	
water quality	4	2	1/4	1	3	1/2	0.143	
distance from waterway	2	1/2	1/6	1/3	1	1/4	0.058	
rainfall	5	3	1/3	2	4	1	0.220	

Table 5. Relative Weights of Prioritization Criteria for Restoration and Conservation of Plain Qanats from a Managerial Perspective

Row	Name of Qanat-city	rainfall	population	flow rate	Area under cultivation	length	depth	distance from waterway	water quality
1	Boshrouye- Boshrouye	0.034	0.32	0.191	0.029	0.244	0.14	0.016	0.366
2	Hajiabad-Birjand	0.082	0.179	0.191	0.070	0.024	0.053	0.050	0.029
3	Hajiabad-Nehbandan	0.082	0.021	0.191	0.029	0.244	0.297	0.016	0.029
4	Mohammadabad-Darman	0.082	0.051	0.068	0.203	0.024	0.053	0.176	0.123
5	Sofla Tabasin-Nehbandan	0.028	0.051	0.068	0.029	0.024	0.053	0.078	0.029
6	Aliabad-Darman	0.085	0.031	0.068	0.351	0.051	0.016	0.185	0.029
7	Nougab- Darman	0.085	0.242	0.068	0.029	0.051	0.053	0.016	0.029

8	Abu al-Khairi-Qain	0.222	0.021	0.068	0.029	0.113	0.053	0.185	0.221
9	Ahmedabad- Darmian	0.098	0.032	0.068	0.203	0.113	0.140	0.185	0.109
10	Haji Abad - Qain	0.201	0.051	0.018	0.029	0.113	0.140	0.084	0.037

Table 6. Relative Weights of Prioritization Criteria for Restoration and Conservation of Plain Qanats from a Technical Perspective

Row	Name of Qanat-city	rainfall	flow rate	length	depth	distance from waterway	water quality
1	Boshrouye-Boshrouye	0.034	0.191	0.022	0.024	0.246	0.366
2	Hajiabad-Birjand	0.082	0.191	0.212	0.125	0.089	0.029
3	Hajiabad-Nehbandan	0.082	0.191	0.024	0.024	0.246	0.029
4	Mohammadabad-Darmian	0.082	0.068	0.212	0.054	0.020	0.123
5	Sofla Tabasin-Nehbandan	0.028	0.068	0.212	0.125	0.045	0.029
6	Aliabad-Darmian	0.085	0.068	0.100	0.392	0.020	0.029
7	Nougab- Darmian	0.085	0.068	0.100	0.125	0.246	0.029
8	Abu al-Khairi-Qain	0.222	0.068	0.048	0.054	0.020	0.221
9	Ahmedabad-Darmian	0.098	0.068	0.048	0.054	0.020	0.109
10	Haji Abad - Qain	0.201	0.018	0.021	0.024	0.045	0.037

Table 7. Relative Weights of Prioritization Criteria for Restoration and Conservation of Mountainous Qanats from a Managerial Perspective

Row	Name of Qanat-city	rainfall	population	flow rate	Area under cultivation	length	depth	distance from waterway	water quality
1	Ersk-Basroiye	0.020	0.192	0.293	0.055	0.092	0.233	0.198	0.030
2	Darmian - Darmian	0.099	0.342	0.293	0.405	0.021	0.014	0.020	0.061
3	Ardakoul-Qain	0.040	0.036	0.175	0.142	0.228	0.233	0.198	0.155
4	Grimonj-Qain	0.099	0.080	0.024	0.090	0.092	0.041	0.106	0.061
5	Qanbar-Sarbisheh	0.040	0.023	0.024	0.024	0.092	0.099	0.198	0.013
6	Sheshtok-Ferdows	0.099	0.023	0.024	0.055	0.021	0.041	0.020	0.155
7	Khan- Darmian	0.040	0.036	0.058	0.090	0.092	0.099	0.020	0.061
8	Apo-Sarayan	0.233	0.192	0.058	0.024	0.228	0.099	0.020	0.155
9	Baraz-Qain	0.233	0.055	0.024	0.090	0.092	0.099	0.198	0.155
10	Kangan-Sarbisheh	0.099	0.023	0.024	0.024	0.040	0.041	0.020	0.155

Table 8. Relative Weights of Prioritization Criteria for Restoration and Conservation of Mountainous Qanats from a Technical Perspective

Row	Name of Qanat-city	rainfall	flow rate	length	depth	distance from waterway	water quality
1	Ersk-Basroiye	0.020	0.293	0.057	0.022	0.017	0.030
2	Darmian - Darmian	0.099	0.293	0.265	0.405	0.177	0.061
3	Ardakoul-Qain	0.040	0.175	0.024	0.022	0.018	0.155
4	Grimonj-Qain	0.099	0.024	0.057	0.120	0.046	0.061
5	Qanbar-Sarbisheh	0.040	0.024	0.057	0.049	0.018	0.013
6	Sheshtok-Ferdows	0.099	0.024	0.265	0.120	0.177	0.155
7	Khan- Darmian	0.040	0.058	0.057	0.049	0.177	0.061
8	Apo-Sarayan	0.233	0.058	0.024	0.049	0.177	0.155
9	Baraz-Qain	0.233	0.024	0.057	0.049	0.018	0.155
10	Kangan-Sarbisheh	0.099	0.024	0.138	0.118	0.177	0.155

Table 9. Final Weight and Ranking of Restoration and Conservation Priority for Plain Qanats from Technical and Managerial Perspectives

Name of Qanat-city	technicalFinal weight	managerialFinal weight
Boshrouye- Boshrouye	1	0.163
Hajiabad-Birjand	2	0.133
Hajiabad-Nehbandan	3	0.125
Mohammadabad-Darmian	7	0.081
Sofla Tabasin-Nehbandan	10	0.063
Aliabad-Darmian	5	0.094
Nougab- Darmian	6	0.083

Abu al-Khairi-Qain	4	0.120	8	0.083
Ahmedabad- Darmian	8	0.076	4	0.105
Haji Abad - Qain	9	0.064	9	0.054

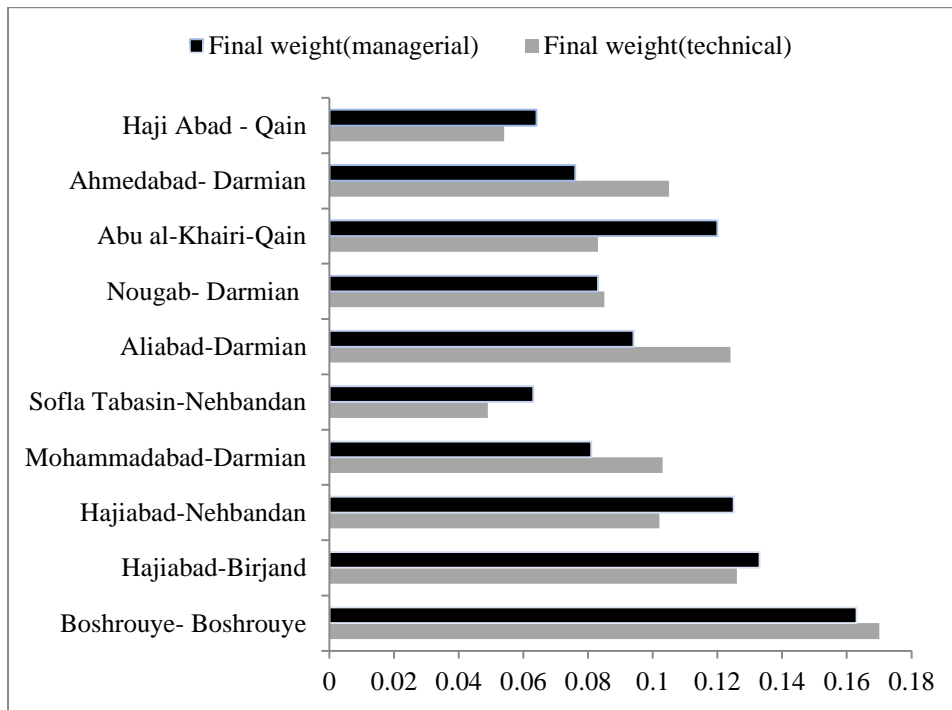


Figure 5. Final Weight and Ranking of Restoration and Conservation Priority for Plain Qanats from Technical and Managerial Perspectives

Table 10. Final Weight and Ranking of Restoration and Conservation Priority for Mountainous Qanats from Technical and Managerial Perspectives

Name of Qanat-city	technical	Final weight	managerial	Final weight
Ersk-Basroiyyeh	2	0.145	2	0.166
Darmian - Darmian	1	0.219	1	0.256
Ardakoul-Qain	4	0.113	3	0.133
Khan- Darmian	8	0.060	7	0.061
Apo-Sarayan	3	0.115	4	0.102
Baraz-Qain	5	0.092	5	0.084
Kangan-Sarbisheh	7	0.081	9	0.043
Grimonj-Qain	9	0.057	6	0.063
Qanbar-Sarbisheh	10	0.029	10	0.034
Sheshtok-Ferdows	6	0.086	8	0.049

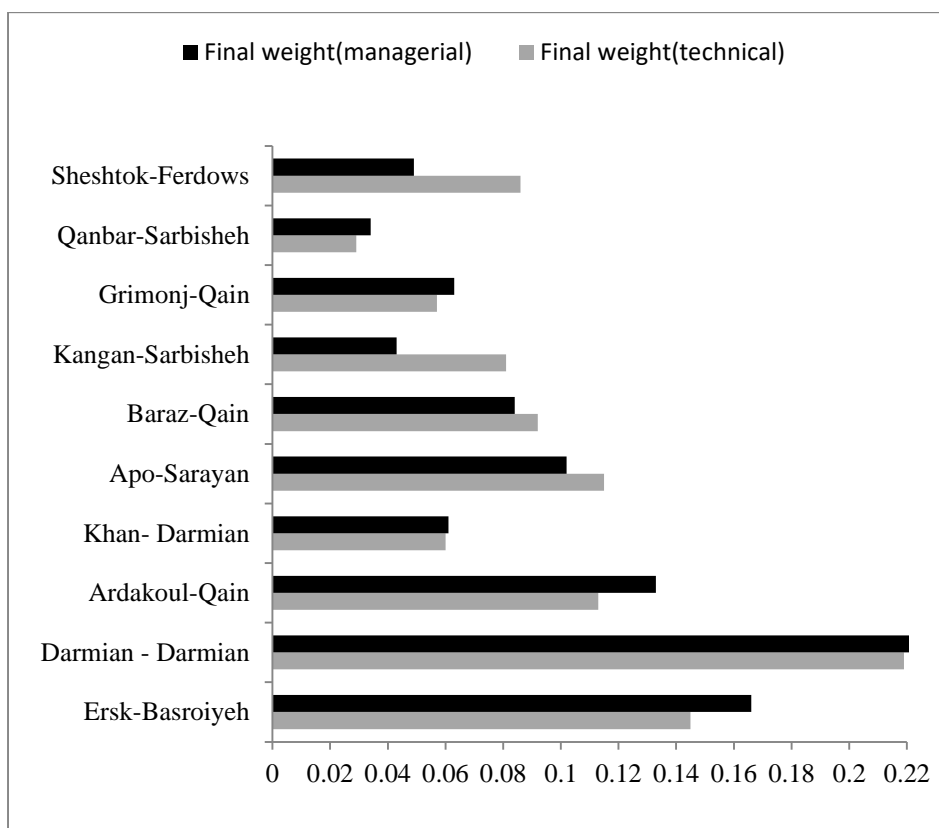


Figure. 6. Final Weight and Ranking of Restoration and Conservation Priority for Mountainous Qanats from Technical and Managerial Perspectives

This research aims to fill this existing gap by introducing the AHP as a scientific and novel method for prioritizing qanat restoration and conservation. The proposed approach can provide a suitable knowledge base for further work in this area. Additionally, using the methodology of this research, qanats that are prioritized for restoration and conservation are those that can achieve desirable water supply within the allocated budget.

In this study, the Boshrouye qanat in the plain qanats group was prioritized for restoration and rehabilitation from both managerial and technical points of view, with weights of 0.170 and 0.163, respectively. Similarly, the Darmian qanat was prioritized for restoration and rehabilitation in the mountainous qanats group from both managerial and technical perspectives, with weights of 0.265 and 0.219, respectively.

It is recommended that the institutions responsible for qanat restoration and reconstruction prioritize the proposed qanats for reconstruction in the initial stage, following the process outlined in this article. Subsequently, the qanats with higher priorities (in proportion to the allocated budget) should be thoroughly examined in the field. This

approach ensures the fair distribution of credits while maximizing the water flow to achieve the most efficient use of costs in the restoration and reconstruction sector.

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Authors contribution statement

H.M conceived of the presented idea. H.M., K.H., and K.S.A developed the theory and performed the calculations as well as validated the analytical methods.. All authors discussed the results and contributed to the final manuscript.

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