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Collaborative water management through revitalizing social power relationships: a social network analysis of Qanat stakeholders in Iran

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Abstract

The network relations of Qanat stakeholders in Iran as an ancient type of water-supply system were considered with the aim of clarifying the societal transformation through revitalizing power dynamics. The present network was highlighted by the interaction of three groups of new actors with the greatest social power: 1. those capable of developing trust and participation ties, 2. those with high control power and high mediation who link small family groups and play a role in empowering individuals, and 3. those who have high fame and are key players by leading thoughts and resolving conflicts. Meanwhile, Boolean Combination Index confirms the increase of various quantitative indicators, such as higher reciprocity and transitivity of relationships and shorter geodetic and diameter index. This study concluded that the revival of power relations in a social–ecological system can be effective in changing the social structure based on the recognition of internal social capitals.

Introduction

Management of natural resources, especially water management, is difficult and complicated for various reasons (Evett et al. 2019). Water management is affected by the interconnectedness of human and natural systems, which carries features, such as being holistic, uncertainty, nonlinearity, dynamic complexity, social stratification, diversity of experiences, and multiple realities (Schneekloth et al. 2020). Ecosystem boundaries of a natural resource are not governed by political and administrative boundaries (Lienert et al. 2013; Sen et al. 2019; Doulgeris et al. 2015). Considering the importance of water resources and the challenges ahead at multiple levels, efficient collaborative management is extremely useful and at the top of countries' plans and priorities (Fliervoet et al. 2016; Sen et al. 2019).

Participation and engagement of local inhabitants are especially important in management processes to resolve conflicts and prevent resource degradation (Braga et al. 2014; Caretta 2015; Fliervoet et al. 2016; Erostate et al. 2020; Sen et al. 2019). Studies show that collaborations are moving toward less formal management through a network of interdependent stakeholders that focus on frequent social learning, information sharing, and, moreover, seeking to develop beyond the performance of state actors (Tengö et al. 2014; Fliervoet et al 2016; Hasselman 2017; Huitema and Meijerink 2017; Sen et al. 2019). Another salient concept that emerges in the literature on both collaborative management and networks is social capital and resilience, which should facilitate coordination across actors and thus make the entire network stronger (Fischer and Ingold 2020). In times of shocks and catastrophes, such as flood events or water scarcity, enhanced social capital and resilience might reduce the vulnerability of affected communities (Fischer and Ingold 2020). Participation of individual stakeholders in collaborative efforts is a critical point for both resilience and transformation of social–ecological systems, in seeking management

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to increase positive outcomes (e.g., sustainability, water security, etc.) as well as to avoid negative ones (Wilson et al. 2013). While many of our pressing sustainability challenges are manifested in nature (Ekins et al. 2019), their resolution requires transformations and transitions on a level of the societal structures, systems, and practices (Díaz et al. 2019; Scoones et al. 2020). Transformations are introduced as wider societal change processes on a level of structure and encompassing human–environment relationships that may also include transitions on a level of delineated socio-technical, socio-institutional, and socio-ecological configurations (Feola 2015; Hölscher et al. 2018). A network structure consists of the ties between members and patterns, and can depict the positions of actors or substructures within the network (Kapucu and Hu 2020).

This article clarifies the relationship between social networks, effective transformation, and reform initiatives. A network is a set of nodes tied together by various types of relationships (Kapucu and Hu 2020). SNA has been used to analyze the structure of relationships pattern among different stakeholders and strategic positions in the network (Liu et al. 2017; Thovex and Trichet 2013). It is considered a tool for the proper management of natural resources and more adaptability (Bodin and Crona 2008; Lienert et al. 2013) by identifying key actors with the most social power, authority, and influence that serve as an important driving force in collaborative water management (Arnette et al. 2010; Fliervoet et al. 2016; Sen et al. 2019). This leads to social power sharing, communication, and conflict resolution in the network. Social power can be defined as the ability of a person to create conformity even when the people being influenced may attempt to resist those changes (Stangor et al. 2022). Power sharing at all levels and among all stakeholders has had a significant impact on the optimal management of water resources (Arnette et al. 2010; Lienert 2013; Sen et al. 2019; Wang et al. 2019). The social network will have a greater effect when people are more essential to it and have easier access to other network members. As a result, these networks are more likely to encourage and value creative or innovative ideas (Wang et al. 2019). Power, authority, and control are all different components of social influence. Power refers to the process of social influence itself; those who have power are those who are most able to influence others (Stangor et al. 2022). While, authority relates to the legitimacy of using this power basis of his experiences and prestige (Morselli and Passini 2011).

Social influence is the process through which social power is wielded in interpersonal contexts via the use of different influence strategies producing a change in the beliefs, attitudes, or behavior of another person (Simpson et al. 2015). In this study, we focused on power relations with the aim of better collaborative management and network dynamics increase of Sadrabad Qanat (SQ) in the central part of Iran. To implement these goals, different quantitative indices of SNA, such as betweenness centrality and degree centrality, are used to determine the degree of social power of individuals (Lienert et al. 2013).

Many studies have been published in the field of natural resource management and the use of social network analysis and its influence. In these studies, researchers have answered various questions that show the unpredictable complexity of social–ecological systems. The most important questions in this regard are as follows: How does a social network affect society (Cowling and Wilhelm-Rechmann 2007)? How can institutional arrangements be used to help better management? How can we employ the mixed-method approach to analyze information sharing (Gogaladze et al. 2020)? How do social networks and social processes influence each other and in turn influence social outcomes (Groce et al. 2019)? In recent studies, the following question is raised: How can institutional arrangements be leveraged to contribute to better management (Riggs et al. 2020)?

This study showed the significant relationship between social networks, successful transformation, and reform efforts in collaborative water management. The importance of this research is understanding how to revive partnerships and change the management structure in a traditional irrigation system (TIS) with the limitation that government institutions and private agencies are not present in the social–ecological boundary of this system. The actors or components that make up a network are not self-sufficient and rely on other actors for resources and information (Shrestha 2018). TIS is community-based and has high cultural, tourist, and ecological values (Finger and Borer 2013). However, many irrigation communities have disappeared in recent decades. The results of some studies show that the survival factor of the TIS is the creation of institutions that enable self-government, communication, and knowledge transfer (Finger and Borer 2013). Research shows that the social and environmental sustainability of the TIS is related to the intensity and nature of social capital. In other words, systems differ in water demand and water efficiency due to differences in irrigation management strategies that are affected by human and structural factors (Scott Jansing et al. 2020). The researchers conclude that these results could help design a mechanism for transition to sustainable irrigation management (Scott Jansing et al. 2020).

This study seeks to evaluate whether the structure of the TIS network can be improved based on internal social capital and without relying on external forces or institutions. The novelty of this study is the investigation of this section. SQ as a kind of TIS was selected for important reasons in this study: 1. A population of over 600 people in the SQ region was dependent on this water-supply system for living. 2.

SQ has been considered a preserver of "social cohesion" in villages (Balali 2009) and as a water-supply system that can provide powerful incentives for community action and supply and management of water resources. The construction of SQ has also been effective in creating employment, reinforcing the structure of social networks and family-based social organization (Stinson et al. 2016). Therefore, its preservation is considered for local agricultural security, including food supply and production for trade, which is crucial to local, social, and political stability (Stinson et al. 2016). Now, with all the mentioned features, proper collaborative management is not being implemented in SQ, and consequently, increasing local conflicts prevent solving water issues and have adverse effects such as land abandonment and migration to urban margins. Water conflicts in Yazd Province have weakened social trust among stakeholders (Islami 2017; Islami et al. 2018).

This paper tries to explain how societal transformation in a TIS can be created or how management relationships can be revived using the social network analysis method with the most power relations and internal social capitals. This study proposes that SNA evaluation of the ancient water system can improve the understanding of the social structure and the possibility for this system to lead to positive results for water management in both resilience and transformation of the social–ecological system. We seek to contribute to understanding diverse arrangements of power relationships in deep-rooted structures, and how they lead to adaptive water management. Specifically, this study explores the following questions:

1. How is the network structure cohesion of SQ in terms of the interrelationships of collaboration and stability at present?
2. Are the current actors able to facilitate the formation of a sustainable TIS without the need for external support?
3. Who are the actors of the SQ network in terms of authority, social influence, and control power?
4. Which actors are essential for filling the gaps in relationships between people?
5. Which actors can lead the thoughts and play an effective role as social entrepreneurs?
6. What results can be drawn from the dynamics of the SQ collaborative structure?

Research method

Geographical location

In this study, we focused on power relations with the aim of better management and increasing network dynamics in SQ in Yazd Province (Iran). The SQ area is located at 53° 30′ to 53° 40′ E, and 31° 50′ to 32° 10′ N (Fig. 1), in the Nadushan Watershed, Iran with an area of 1249 km^2. SQ has an age of 200 years and has two strings with a length of about 5000 m, 50 rods, an 8 day turn of water flow between 66 stakeholders, and the share of water divided on an hourly basis. Sharing (allocation and distribution), restoring, and dredging of Qanat, constructing and repairing water-supply channels, constructing and restoring reservoirs, and monitoring irrigation are the most important hierarchy activities of irrigation under cultivation of about 70 ha of lands, that dominate the cultivation of wheat, saffron, and orchards.

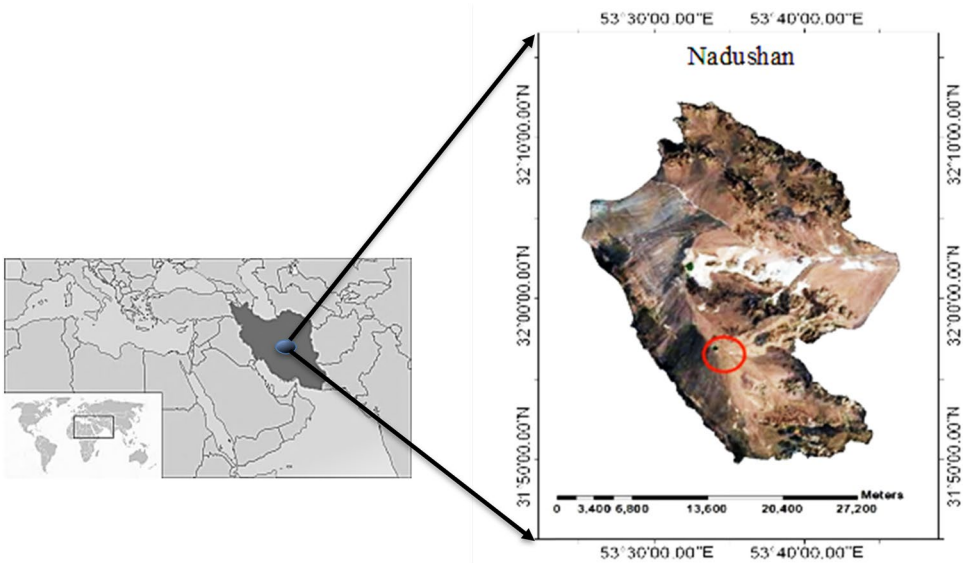

Fig. 1 Geographical Location of Sadrabad Qanat in Nadushan Watershed, Yazd Province, Iran

Method and data sources

The strategy used to collect stakeholders' relationships was the complete network approach, in which participant actors and demographic relationships were censored by the interview method and questionnaire tools for 5 months of fieldwork, which started from April to August 2020. In the study area, there were 66 water stakeholders on 743 ha of land. Two methods were used to identify the participants' networks and receive the communication data: (1) a list of all Qanat participants was prepared based on the available information, and a face-to-face survey was conducted; (2) the snowball method was also used allowing to include new individuals who were not considered in the first list, and hidden links were discovered. This process was continuing until no new actors were identified (Hanneman and Riddle 2005; Scott Jansing et al. 2020). Reciprocated collaborative ties were used to do the social network analysis, because the data on these actors (with mutual relationships) are stronger and with fewer errors (Fliervoet et al. 2016; Stein et al. 2011). The respondents were interviewed on the basis of the following criteria: (1) they represent one of the 66 listed stakeholders; (2) they have a high position in Qanat water management, such as director or manager. With this selection, we ensured that respondents could represent the collaborative relations of their groups or families. The relationships of participation and trust between stakeholders were assessed in a separate network analysis questionnaire. Each of the two trust and participation matrices was produced based on identifying their trust or collaborative relationships. Information analysis, graph drawing, and data matrix entry were performed using UCNET 6.528 and Netdraw 2.141 software. This software, created to analyze and visualize social networks, contains a package of Pajek and NetDraw software. At this stage, the stability of the network structure and the strength of each link (the amount of communication of individuals) in each matrix were determined. Density, reciprocity, network size, centrality (in- and out-degree), and betweenness centrality were used to describe the network in this study. The purposes of using these SNA indices are as follows: network density index to analyze coherence and efficiency (Olsson et al. 2004; Sandström and Rova 2010), reciprocity degree to study the mutual trust and mutual participation of people (Hanneman and Riddle 2005), and reciprocity index to identify the social capital of the network and the resilience of the system against environmental stresses (Leahy and Anderson 2008). Degree centrality can be calculated based on the number of actors directly related to the focal actor, regardless of the direction and value of the communication. This centrality has one type in unidirectional graphs and two types, in-degree and out-degree, in directional graphs. A high degree of out-degree reflects the influence of the actor, meaning that this node can propagate information much faster (Bodin and Crona 2009; Sandström and Rova 2010). A high degree of in-degree reflects one's level of authority and fame. That is, many people pay attention to this node and people with high levels of in-degree receive more ties (Bodin and Prell 2011; Sandström and Rova 2010).

Betweenness centrality index, as a benchmark to recognize the power of each person to control the flow of resources in the network, the degree of actor mediation, and identifying the actor with the role of the bridge in the network are considered in this paper. Betweenness centrality $C_B(v)$ for a node v is defined based on the following equation:

$$C_B(v) = \sum_{s \neq v \neq t} \frac{\sigma_{st} - (v)}{\sigma_{st}},$$

where σ_{st} is the number of shortest paths with nodes s and t as their end nodes, while $\sigma_{st}(v)$ is the number of those shortest paths that include node v (Freeman 1977). High centrality scores indicate that an actor lies on a considerable fraction of the shortest paths connecting pairs of nodes (Raghavan Unnithan et al. 2014). In the next stage, the BCI for combining trust and participation matrices was used to determine the key stakeholders in the collaborative network. Finally, the new network structure and power relations identified based on the combined matrix (the set of actors with the highest degree of centrality of trust and social participation) were re-analyzed in terms of stability and compared with its primary state.

Results

Network cohesion analysis of trust and collaboration networks

This section is the answer to the first question of this study. The network structure's cohesion and stability in this study were evaluated based on the indices of density, reciprocity, transitivity, components, fragmentation, diameter, average distance breadth, and compactness.

The results show that the structure of trust and collaboration networks is not strong enough. The density analysis indicates that the degree of dyadic connection in the population of Qanat stakeholders is very low (less than one-fifth of possible relationships are realized) and this has led to a very low level of social capital and information transfer in the network. Mutual relationships between stakeholders (both directions) are very weak too (the reciprocity values which are 0.264 and 0.204) in both participation and trust ties, which leads to the weakening of the establishment of social trust relations between actors, as

well as a reduction in collective activities in water management. The values obtained show that only one-fifth of the ties in the two networks are reciprocal. The transitivity index, which is another important index in answering the most basic questions of social structure with respect to triads, expressed a low value of 0.386 for the trust ties and a medium value of 0.437 for the collaboration ties (better transitivity). The triad allows for wider relationships, and all of the really fundamental forms of social relationships can be observed. The average distance between the trust and collaboration networks is 2.133 and 2.114 steps, respectively. To reach the actors showing a slow flow of information on these networks with the same diameter of 5 (where the 'diameter' here means that five actors have taken a path through the network), there is a difference in the number of components (including 7 in the collaboration network versus 3 in the trust network). All measure definitions may be found available in Table 1.

Despite the weak superiority of each network in one or more indices (showing the difference in the number of actors and the extent of their connections in a network), in general, two networks do not have a significant advantage in terms of the strength of their structure. For more reassurance, distance-based cohesion (compactness) and distance-weighted fragmentation (Breadth) analysis were performed, which confirm that the conditions are almost equal in these two networks (being in the medium and near low range (40–60%) of both indices in these networks). Here, the fragmentation of the network due to the separate components and especially the actors who cannot reach each other (failure to establish reciprocal and triad links and finally the improper network density) is a serious obstacle to the cohesion, unity, and integration of the actors managing the Qanat collaborative water management.

In- and out-degree centralities in trust network

This section is the answer to the second question basis of trust network. The centrality index in trust and participation ties indicates the degree of centrality and social power of the individuals in the network, which can play a key role in water management. The results indicate that the three stakeholders of S.E.M, AH. J, and S.J.M have the highest in-degree centrality of 88%, 86%, and 86%, respectively (Fig. 2), which means that they hold a central role in the network.

They also have higher authority and fame than other stakeholders in the network. This means that many people refer to these nodes and receive more in-degree ties, so these will be key stakeholders in the collaborative management of water resources. On the other hand, AH. J has also a high out-degree centrality. The 100% out-degree centrality indicates a very high social influence of this stakeholder and is therefore considered a key player in the network among water stakeholders, so it could well play a high control role in the network. Actors like MO. J, AB.MO, and ES.SA

Table 1 Network cohesion analysis of trust and collaboration

Metrics	Relation values		Range and explanations UCINET definitions of multiple cohesion measures (Borgatti et al. 2002; Hanneman and Riddle 2005)
	Trust	Collaboration	
Density	0.177	0.176	Number of edges divided by the maximum possible number of notes that the diagonal is ignored. Values closer to 1—better connectedness of the actors in the network
Transitivity	0.386	0.437	T = 1 implies perfect transitivity, i.e., a network whose components are all cliques. T = 0 implies no closed path of length two, which happens for various topologies, such as a tree or a square lattice
Hybrid reciprocity	0.264	0.204	In the hybrid method, the overall and node-level reciprocity values are the same as in the dyad-based model
Components	3	7	Number of weak components
Component ratio	0.031	0.092	Number of components minus one divided by the number of actors minus one: 1—every node is isolate; 0—there is one component
Fragmentation	0.030	0.119	Fragmentation refers to the proportion of pairs of nodes that cannot reach each other. If fragmentation is > 0, the graph is disconnected
Average Distance	2.133	2.114	Average geodesic distance between all pairs of nodes (the time length for information diffusion across the network). The rate of information flow increases with decreasing value of average distance index
Diameter	5	5	Length of the longest geodesic and the longest path of the information flow (between the furthest nodes in the network)
Breadth	0.475	0.515	Distance-weighted fragmentation (1 minus the compactness)—lower bound of 0 when every pair is adjacent to any other one [entire network is a clique (fully connected clusters)]—minimum breadth—upper bound of 1 when the graph is all isolates
Compactness	0.525	0.485	Distance-based cohesion (the mean of all the reciprocal distances)—range 0–1; larger values indicate greater cohesiveness

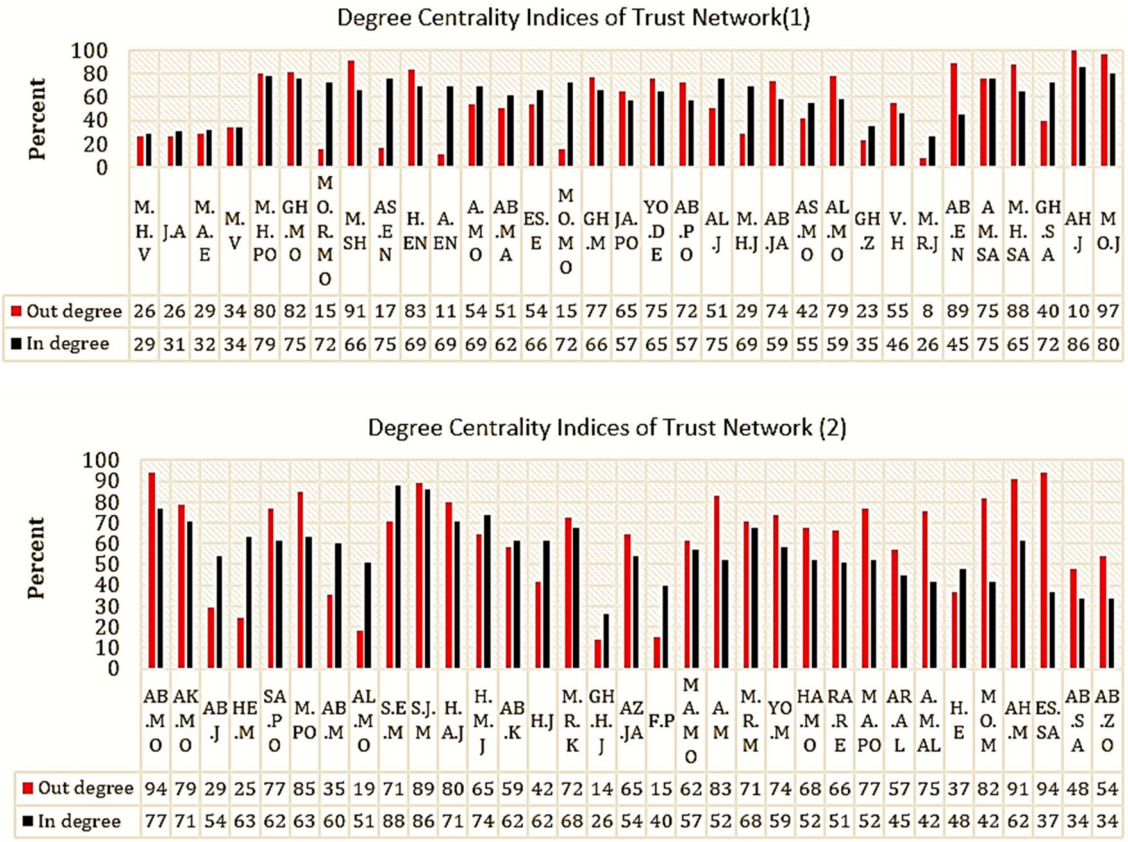

Fig. 2 In- and out-degree centrality indices in trust network of SQ stakeholders (1 & 2)

have a high level of out-degree centrality in trust. Based on these results, these actors can be effective in developing and expanding trust in the network. Instead, some actors, such as M.R. J, A. EN, and GH.H. J, have a low centrality index in the trust network and therefore have less power in the network and cannot be considered effective contributors to the trust ties. However, efforts were needed to establish a platform for trust and strengthen their trust ties. These actors have less influence and authority than others and receive less support.

In-degree and out-degree centrality indices in participation network

Similar results of the trust ties analysis occurred with respect to the in-degree centrality index in the participation ties. This section is the answer to the second question basis of participation network.

As a result, there are three actors of S.J.M, S.E.M, and AH. J with the highest in-degree centrality in the participation network, respectively. They get more participation ties than other people in the network, so they have high authority and are key stakeholders with full-fledged social power in the participation network. Four actors of GH.M, AB.PO, H.A. J, and AB. ZO had a 100% out-degree centrality index in the participation network. Those identified with high social influence in the network would be able to play key roles in managing water resources in this area as key stakeholders in collaborative water resource management. Figure 3 shows the indices of in-degree and out-degree centralities of participation ties among stakeholders participating in the management of SQ.

Results of the analysis of betweenness centrality index in trust and participation networks

This section is the answer to questions 4 and 5 of this study. The results showed that people with a higher degree centrality index also had higher percentages of betweenness centrality index, so that those with high authority had higher control power and more mediation power. Thus, in the trust network actors, such as AH. J (with betweenness centrality of 3.1), SEM (with betweenness centrality of 1.9), and SJM (with betweenness centrality of 2.2), like the degree centrality index, also had a high degree of betweenness centrality. The average degree of betweenness centrality in trust and participation ties was 0.64 and 0.77, respectively.

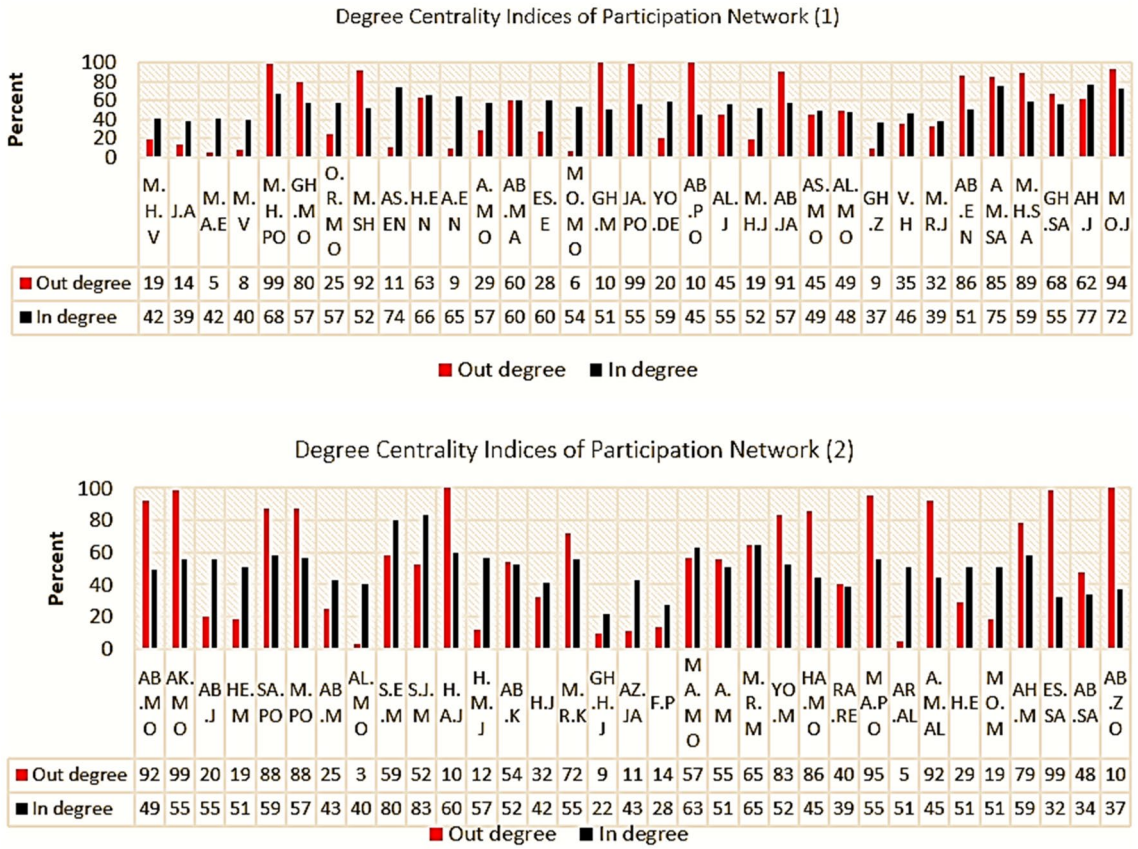

Fig. 3 In- and out-degree centrality indices in participation network of SQ stakeholders (1 & 2)

However, there were actors in the participation network that did not rank high in the degree centrality index but had a high level of betweenness centrality in the participation tie that could be assigned to MO. J (with 3.6 vanguard of the highest degree of betweenness), AM.SA, and MHPO (with a betweenness degree of 3). In terms of influence and authority, they did not have a good status but could play the role of mediation, which was very important. These individuals, discovered in the two networks of trust and participation, are higher than the average betweenness centrality of the two networks and are able, as important network mediators, to create information flows between other actors by creating inter-group ties that are crucial to network integration and quickly provide information sources to other actors. At the same time, these individuals with high betweenness centrality can play an important role as social entrepreneurs in the dynamics of management, which is a unique feature of a network. Table 2 indicates detailed results of betweenness centrality index for each of the stakeholders in both networks.

Both trust and participation factors are of particular importance in the management of water resource networks. At the network management of SQ, key actors in the trust and participation ties were somewhat different. Here, there is an actor who has a high percentage of out-degree centrality index and was not in the in-degree centrality index list. Therefore, we need to look for key actors that have high scores in both trust and participation networks. These actors, which can have a high degree of centrality in both trust and participation networks, are in fact the social powers of the network governance of Qanat and indeed the social partners in collaborative management. For this purpose, we sought to identify these individuals by combining the trust and participation matrices.

Results of the analysis of Boolean combination index (BCI)

From the evaluation of the coherence of the cooperation structure, it was found that the aqueduct network has weak stability. Therefore, this research organized the initiative of combining networks of participation and trust with regard to the need for more powerful actors. Based on the Boolean index, new actors were identified that led to the increase of various network indicators (see Table 3 and compare it with Table 1).

Table 2 Extraction number of betweenness centrality index in the trust and participation ties

Abbreviation Name	Betweenness centrality index		Abbreviation name	Betweenness centrality index		Abbreviation name	Betweenness centrality index	
	Trust	Participation		Trust	Participation		Trust	Participation
M.H.V	0.1	1.1	AS.MO	0.2	0.2	H.M.J	0.9	0.1
J.A	0.1	0.6	AL.MO	0.6	0.4	AB.K	0.5	0.6
M.A.E	0.1	0	GH.Z	0.1	0	H.J	0.2	0.1
M.V	0.2	0.2	V.H	0.6	0.2	M.R.K	0.9	1.4
M.H.PO	1.5	3	M.R.J	0.1	0.6	GH.H.J	0	0
GH.MO	1.3	0.6	AB.EN	0.9	1.1	AZ.JA	0.7	0.1
MO.R.MO	0.1	0.1	AM.SA	1.1	3	F.P	0.1	0
M.SH	1.3	1.3	M.H.SA	0.6	0.9	MA.MO	0.3	1
AS.EN	0.3	0.2	GH.SA	0.3	0.5	A.M	0.6	0.2
H.EN	1.3	1.2	AH.J	3.1	2.1	M.R.M	0.7	0.7
A.EN	0.1	0	MO.J	2.1	3.6	YO.M	0.8	0.5
A.MO	0.5	0.2	AB.MO	1.8	0.4	HA.MO	0.2	0.5
AB.MA	0.4	0.6	AK.MO	1.1	1.4	RA.RE	0.3	0.1
ES.E	0.5	0.4	AB.J	0.3	0.2	MA.PO	0.5	1.3
MO.MO	0.1	0	HE.M	0.1	0.1	AR.AL	0.2	0
GH.M	1	1.2	SA.PO	0.7	1.1	A.M.AL	0.4	1.5
JA.PO	0.5	1.2	M.PO	1	2.1	H.E	0.2	0.2
YO.DE	0.9	0.2	AB.M	0.2	0.1	MO.M	0.4	0.1
AB.PO	0.6	0.6	AL.MO	0.1	0	AH.M	0.9	0.5
AL.J	0.8	0.8	S.E.M	1.9	2.8	ES.SA	0.5	0.3
M.H.J	0.3	0.1	S.J.M	2.2	2.8	AB.SA	0.2	0.1
AB.JA	0.6	1.2	H.A.J	1.2	2.3	AB.ZO	0.2	0.8

Combining the trust and participation matrices through Boolean combination index showed that three actors of AH. J, S.E.M, and S.J.M had a higher in-degree centrality index in the network (Fig. 4).

They were found to have higher trust and participation scores than others and to be key actors among other social powers of the network management. The fame and authority of these people are definitely effective in the favorable management of SQ which has various challenges. In addition, stakeholders like AB.MO, ES.SA, MO. J, M.SH, M.H.SA, and M.H.PO had higher out-degree centrality and a higher level of social influence than others, so executives can use these actors who have high social capital in the trust and participation ties to use their influence, fame, and social authority that are instrumental in the success of managing and organizing programs related to Qanat.

Combined matrix graph and indices analysis from BCI

Here is a schematic representation of the final model of the combination matrix of trust and participation ties in Qanat management for those individuals who have only mutual relationships for the purpose of visual analysis and comparison of individuals in Fig. 5. In this graph, the size of nodes represents the number of reciprocal relationships of each actor (the number of mutual relationships of actors). Here, actors with more mutual relationships are usually recognized as social network assets and can be used to reduce environmental stresses and increase resiliency and adaptive water management.

Analysis of network indices at a new combination matrix (including new actors with the most centrality) shows a significant increase in metrics. Table 3 shows the results of this section.

Discussion

Assessing the network structure from the perspective of sustainability and social cohesion

Our first question was to evaluate the sustainability of the network structure of SQ based on the relationship between density index and social cohesion (Olsson et al. 2004). Density index analysis indicated a network with moderate social

Table 3 Boolean network values of metrics based on new power relations

Metrics	Density	Transitivity	Hybrid Reciprocity	Components	Component ratio	Fragmentation	Average distance	Diameter	Breadth	Compactness
Boolean network values	0.434	0.684	0.379	1	0	0	1.606	3	0.290	0.710

stability and cohesion, which represents a low potential for community activities and low network stability that is at risk of disruption and loss of network cohesion. In other words, this network management is able to become a cohesive network with high bridging social capital if it focuses more on creating the right context for participation and trusting practices among actors (especially in the area of water allocation and distribution).

This study revealed that this network structure does not currently have high stability and social cohesion to solve collaborative water issues, so it is necessary to increase density in this network, which has a positive relationship with cohesion and social capital, to increase trust between stakeholders and facilitate sharing information and resources to enable social participation within the network (Bodin and Prell 2011; Koutsou et al. 2014; Lienert et al. 2013; Newig et al. 2010). In particular, the relatively good trust between stakeholders makes it easy to (Chaffin et al. 2014) achieve adaptive management [average upward density index in trust network] (Davenport et al. 2007; Islami 2017; Stern and Marc 2008; Stern 2008; Marc et al. 2015) with more success and less cost (Bodin and Crona 2009; Bodin and Prell 2011; Islami 2017).

A challenge in the network management of Qanats is the increasing social conflicts, which is also confirmed by the reciprocity index. The reciprocity index of the participation network represents constructive interactions (Hanneman and Riddle 2005), which are weakly evaluated here. This indicator shows that the extent of the institutionalization of participation ties is not balanced.

In the trust network, the reciprocity index is better. In the participation network, in addition to the overall lack of interconnections, the lack of interactions at the collective level has created hierarchical structures among the stakeholders, pointing out that the information and impacts are mainly from one to the other without any feedback (Matous 2015); therefore, the network stability is reduced.

According to the negative impact of this index on the social capital of water management network, it can be expected that the community of Qanat stakeholders will be vulnerable. As Leahy and Anderson (2008) pointed out, to achieve resilience in the face of environmental stresses, such as droughts at a lower cost, it is necessary to increase the degree of sustainability and reciprocity relationships of the stakeholders' network.

To form and accelerate mutual trust, adherence to norms, strengthening local traditions, and customs can be developed (Plickert et al. 2007), paying attention to the impact of family networks on the exchange of water and the allocation of Qanat, and strengthening the sense of responsibility for the optimal use of water resources. Considering the direction of the links in measuring relationship ambiguity has been mentioned as an important factor in natural resource community management (Matous 2015; Pretty and Ward 2001);

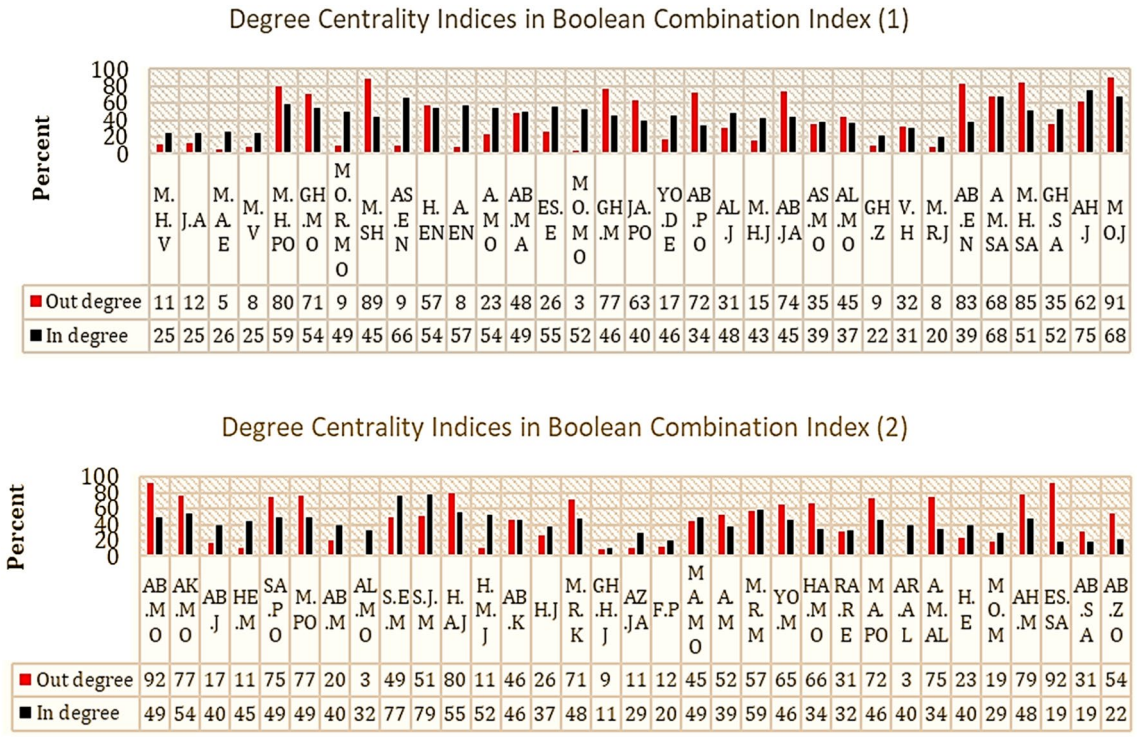

Fig. 4 In- and out-degree centrality indices in BCI (1 & 2)

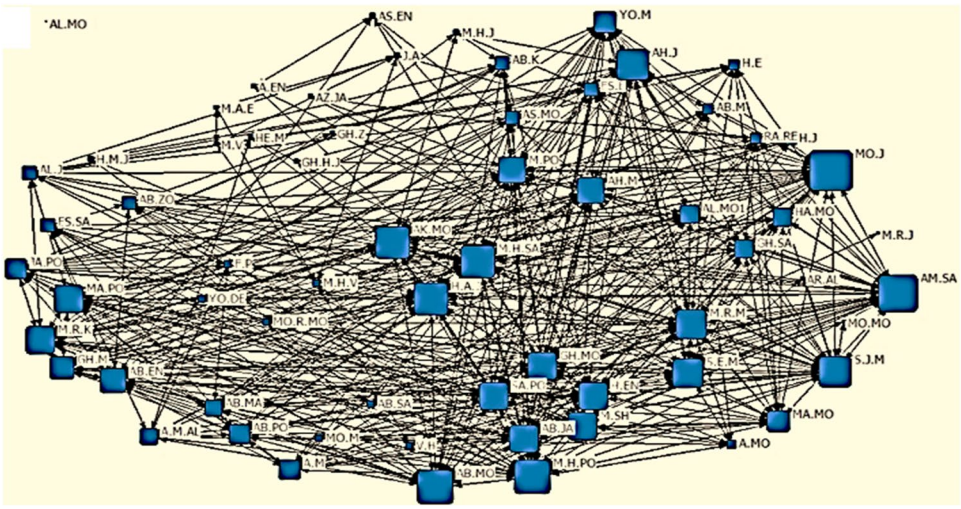

Fig. 5 A combined matrix model of trust and participation ties in network governance of SQ

therefore, this study focused on the two-way relationship in the local Qanat community.

Evaluation of social powers and centralities in the network management

We sought to identify key players with unique, powerful, and influential positions in the Qanat collaborative management. Based on our research, we can say that the network management of SQ is a central network, because there are many ties in the trust and participation network from which a number of important nodes are emitted. In other words, there is a huge difference between the numbers of ties per node (Matei 2011). From the network analysis, it was found that the actors like S.E.M, S.J.M, and AH. J achieved the highest in-degree centrality. This indicator, as indicated by Bodin and Prell (2011), Olsson et al. (2004), Sandström and Rova (2010), represents the fame and high authority of the actors in the network and the high number of references to

them. The same three actors also showed the highest degree of in-degree centrality in the participation tie.

In a separate examination of the out-degree centrality of trust and participation networks, actors like AH. J GH.M, AB.PO, H.A. J, and AB. ZO were topped by a hundred percent. These actors can be effective in developing and expanding trust in the stakeholder's network. A high out-degree of centrality has been identified indicating an actor's social influence, and these nodes can disseminate information much faster (Bodin and Crona 2009; Sandström and Rova 2010). In fact, most of the nodes that originate from these nodes refer to other nodes.

The results of combining the trust and participation network matrices to find the most preferred actors in the two indices of in- and out-degree centralities showed that stakeholders with the highest in-degree centrality in trust and participation matrices also got the highest percentages in the BCI (actors such as AH. J, SEM, and SJM). However, in the out-degree centrality index, the results were different from those in the previous case and the individuals like AB.MO, ES.SA, MO. J, M.SH, M.H.SA, and M.H.PO got top scores. Here, the BCI has revealed more hidden actors. Our understanding of the larger number of actors with multiple attributes is very important for community management.

Here, we have identified the influential and famous actors in the trust and collaboration network. The influence of a recognized actor does not necessarily mean that they are powerful and that their fame can be overlapped with face, not with power. In most cases, power shows a social base, but fame is not the same, and one can have a high base while having power and being famous as an unreliable person. In this study, we measured the actor in terms of the betweenness centrality index to identify social powers (Lienert et al. 2013). With this index, we sought to identify those who have gained power by being on a narrow communication path (the geodesic path), and all communication between the other nodes passes through them (Matei 2011).

People such as S.E.M, AH.J, M.H.PO, MO.J, AM.BA, and S.J.M who achieved the highest betweenness centrality in the collaborative network are in a high-risk position, because they are actors bearing significant pressure (Tsvetovat and Kouznetsov 2011). Actors identified with high betweenness centrality were among the selectors of the BCI (combining the two matrices of trust and participation), meaning that they had all three characteristics of fame, influence, and social power, and were among the chosen to work in collaborative management. Power is associated with high esteem and social influence on identified individuals, and as Henrich and White (2001) pointed out, individuals without power lack the ability to compel others, so these actors are found to have absolute superiority over others. Betweenness centrality is a distinctive feature of centrality indices, and it properly examines its competitors who have nothing to do with it and are structurally equivalent to it. Identifying an actor in the network management with the highest degree of betweenness centrality is important, because it enables us to identify boundary connectors, i.e., bridges between two or more communities that have no other way of communicating (and the structural holes between them), and as Burt has shown, people who bridge between structural holes (mediators), because they relate to sub-communities together, have a greater variety of ideas. They are exposed to a greater variety of ideas (Burt 2004), and they are very important for cultural innovations of all kinds.

As Bonine (1982) points out, Qanat stakeholders' network requires actors of high betweenness centrality to activate and develop an irrigation culture among its stakeholders, which is rooted in their history and culture, and SQ is not exempted from this rule. The identified actors with the highest index of betweenness centrality as community mediators have a significant impact on enhancing the social cohesion of the entire network and rapid sharing of information through access to information that is reliable, diverse, and well timed. They play an important role in the network management of Qanats with their ability and capability in entrepreneurship. This high level of social cohesion and sustainability does not exist in the collaborative network of SQ and requires intermediaries that enable the sub-community (different tribes) to collaboratively solve large-scale Qanat issues. These mediators also play a role in collaborative management in addition to those mentioned as social entrepreneurs (Bodin and Crona 2009; Brandes and Erlebach 2005; Hanneman and Riddle 2005). They have a greater opportunity to create innovation and, of course, grow faster than others. As can be seen from the evaluation of the BCI in the hybrid network (Table 3), the level of each of the indices of social structure increases by the addition of new actors with the most centrality and power relations from within the collaboration network itself and without the need for outsiders. Therefore, in response to the second question of this research, it is confirmed that the current actors are able to facilitate the formation of a sustainable TIS without the need for external support. This study confirms the results of Hölscher et al. (2018), Diaz et al. (2019), and Scoones et al. (2020). According to the obtained results, transformation among actors is an important factor in starting the process of social change in a network. Meanwhile, it is clear to us that the indices of reciprocity and transitivity are directly affecting social capital, and due to the weakness of these two factors in the study area, changes in power composition have played an effective role in increasing social capital and information transfer between stakeholders. Thus, this study confirms the results of Leahy and Anderson (2008) and re-emphasizes the results of Wilson et al. (2013) who see it as a critical point in resilience.

Conclusions

In this study, we found that to decentralize the process of collaborative water management of Qanats, it is necessary to diversify the organized form of interactions with the identified actors, so that different actors perform synchronization and communication to deal with issues without having only one focal actor to take the management (here in the Qanat management field, the only focal actor can be named AH. J). These elite groups, which have unique influence power in the SQ network through interactive interactions and the development of a sense of belonging to a group, can develop trust-based relationships and provide the basis for network dynamics. For this purpose (increasing the network dynamics), we highlighted the network structure of the three groups of outstanding actors who have primary responsibility as follows: (1) Introducing the highest out-degree of centrality actors (expressing authority and social influence) who are highly capable of developing trust. (2) Higher control power over the intermediary position that will connect subcommunities and increase the social cohesion of the entire network. At the same time, it provides access to reliable and varied information and facilitates socio-cultural development. They also contribute to the creation of a self-reliant, entrepreneurial, empowered, and sustainable livelihood community with the power of innovation and creativity. (3) Introducing high in-degree centrality actors who have high fame in the network and thereby help us collaboratively manage water resources as key stakeholders in influencing thought leadership. They are also key management tools in resolving conflicts among stakeholders and more dynamics of the collaboration network.

Moreover, this study, on the basis of analysis, has proposed new but missing actors that provide actors interaction gaps in an organized network that provides efficiency, creativity, dynamism, information sharing, transparency, and responsibility principles.

Based on the results of this study, since social power is in the hands of different actors who in many cases are (1) informal and hidden in the water network and (2) their identification requires measuring different centralities indices, it is recommended to design an intelligent system for continuous monitoring of social capital based on social network analysis.

This proposed system, considering the expansion of virtual communication space and the high use of applications in informing and performing people's daily affairs, seems to be feasible, which can be examined in future studies. More importantly, this study highlighted the restructuring and social transfer by analyzing the internal social capital network. It is suggested that, in future studies, the researchers examine the impact of external social capital and their stakeholders' role in the internal transformation of the traditional water management network. In future studies, the question is whether and how, in the face of the lack of internal social capital, one can rely on external forces to maintain the stability of the TIS. This issue is necessary due to the increasing trend of rural migration and the aging of the community of Qanat water users and other users of traditional irrigation systems in Iran and in other parts of the world with similar conditions.

Appendix 1

Network Analysis Questionnaire of Sadrabad Qanat (SQ)

Q1: Please think back on the most recent decision you had to make regarding water management in SQ

Did you discuss this decision with any person or organization?

If yes, who was that person/organization? You may list more than one

Q2: Are there certain places or events (e.g., Water sharing/Water division/water supply/Repair the wells and channels, etc.) where you most often tend to discuss water management issues pertaining to SQ?

If so, where are these places, and with whom, at these places, do you converse about SQ water management issues?

Q3: Are there any other individuals, government agencies, non-government agencies, or NGO with whom you discuss Qanat water management issues pertaining to SQ?

Q4: Finally, think back to the last time you had a disagreement or dispute regarding SQ water management issues:

Who was the person or group with whom you had this dispute?

Based on the results provided by the respondents, we also asked respondents a series of follow-up 'name interpreter' questions. These questions allowed us to gather more detailed information on the nature of the tie, and they included the following:

Q1: How frequently do you interact with this person or group? [] very rarely [] a few times/year [] monthly [] weekly [] daily (Please note: We inputted the above data as 1 = very rarely…5 = daily)

Q2: How would you define your relationship to them? Select as many as apply: [] colleague [] family [] friend [] employee [] neighbor [] other

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used in the research is proprietary, and derived data supporting the findings of this study are available from the first author on request.

Declarations

Conflict of interest We have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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