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Socio-hydrological analysis: a new approach in water resources management in western Iran

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Abstract

Human consumption patterns have a significant impact on the amount of available water. However, the human effect on water resources is perceived to have been poorly studied. For the effective management of water resources, social and hydrological components should be studied. To fill this gap, the aim of this study was to investigate the socio-hydrological system of the Gavshan Dam in western Iran. Therefore, the qualitative method and root cause analysis (RCA) were used to investigate the causes of the imbalance between water consumption and water resources. Root cause analysis was used to investigate the perceptions of 87 farmers and extension experts from Kermanshah province in Iran. Participants were chosen using the snowball technique and interviewed using a semistructured questionnaire. The results showed that the ineffective administrative structure was the most important and fundamental cause of water management inefficiency, accounting for 48.49% of the total inefficiency. Furthermore, the community sensitivity component (1.34%) indicated that the socio-hydrological system in the studied basin is not fully understood and that network users are not concerned about water crisis and environmental degradation. Poor yield, low income of farmers, reduction of cultivated area, social instability, and lack of secondary agricultural jobs are the main reasons for mismanagement of water resources. Conceptualizing water challenges based on the socio-hydrology revealed by this study can help designers focus on the fundamental causes, discover opportunities for policy, and implement sustainable water management strategies.

Keywords: fishbone analysis, Gavshan Dam, human–water coevolution, Pareto chart, root cause analysis

Introduction

In agrarian societies, the socioeconomic system is based on naturally occurring and renewable resources such as water and soil. Water scarcity is at the core of many of the modern-day sustainability challenges that humans face (FAO 2017; Frascari et al., 2018; Liu et al., 2023). Water scarcity is caused by several factors such as frequent droughts, climate change, prevalent management inefficiency, and lack of attention to socio-cultural potentials (Jalilov et al., 2018). The integrated water resources management (IWRM) approach has been accepted internationally as the way forward for the efficient management of water resources. Integrated water resources management is a process that promotes the coordinated development and management of water, land, and related resources, to maximize the resultant economic and social welfare (Nagata et al., 2021). The IWRM approach focuses on watersheds to deepen the understanding of the characteristics and relationships of the water cycle and considers society as an external variable in the water cycle. In contrast, the socio-hydrological approach treats humans as an internal variable in water cycle dynamics and attempts to understand and predict water management over long-term scales (Mostert, 2018). In 2012, the socio-hydrology approach was introduced to understand the interactions and mechanisms of socio-hydrological dynamics for developing macro-level water management theories (Sivapalan et al., 2012). The socio-hydrology approach observes emerging phenomena in coupled human–water systems and explains how human–water interactions have unintended consequences (Yu et al., 2017). Recent studies (e.g., Di Baldassarre et al., 2019; Enteshari et al., 2020) have reported emerging phenomena and human–water interactions in feedback loop systems that either strengthen or decline water scarcity. Lack of understanding human–water interactions weakens effective management in the long term (Pouladi et al., 2022). In socio-hydrology, two-way feedback between human and water systems is considered part of the water cycle, and the aim is to improve the water system (da Silva & de Souza, 2023; Distefano et al., 2020). The socio-hydrological literature has developed a variety of theoretical frameworks to understand human–water linked systems, such as the Murrumbidgee Basin in

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Australia (Roobavannan et al., 2020), Zayandehrud River basin in Iran (Enteshari et al., 2020), reservoir management in the city of Brisbane, Australia (Albertini et al., 2020), the Campaspe catchment (primary river) in the North-Central region of Victoria, Australia (Iwanaga et al., 2020), agrarian communities dependent on local water resources in the Peruvian Highlands (Oshun et al., 2021), and transboundary rivers (Ghoreishi et al., 2023; Roobavannan et al., 2017; Wei et al., 2022).

This study focused on the socio-hydrology systems related to the Gavshan Dam. For this purpose, the components of the socio-hydrological approach including basin hydrology, population dynamics, basin economy, ecosystem services, community sensitivity, and behavior actions were studied (Di Baldassarre et al., 2019). The component of basin hydrology encompasses the quantity and quality of groundwater and surface water resources. The component of population dynamics explores the environmental factors affecting demographic variations in addition to their short-term and long-term variations. Economic gain is another factor considered in social hydrology, as farmers move to more profitable cropping patterns with minimal environmental conservative practices due to unfavorable financial conditions. Economic growth can continue as long as ecosystem services are not jeopardized (Pouladi et al., 2019). The component of community sensitivity refers to human societies' concerns about livelihood and environmental health, which are influenced by water availability during dry or wet periods. The component of behavioral actions refers to the reactions of human communities to changes (Mostert, 2018). Given the importance of the coupled human–water systems in WRM, numerous studies (e.g., Luu et al., 2022; O'Keeffe et al., 2018; Perera & Nakamura, 2022; Shibata et al., 2022; Yu et al., 2017) have been conducted in the last decade. Some of these studies used a quantitative method to develop the coupled human–water model in socio-hydrology systems. The socio-hydrology systems modeled include interactions between water use and drought (Pouladi et al., 2022), interactions between climate and socio-hydrological systems (Darvini & Memmola, 2020), water resources management (Carr et al., 2022; Halder et al., 2021), and farmer adaptability to hydrological changes (Kumar et al., 2020).

Challenges in using quantitative methods for socio-hydrological modeling include insufficient data for numerous variables (Mostert, 2018). For this reason, when quantitative information on some socio-hydrological factors is missing, it is useful to use qualitative approaches to obtain some information on these factors and processes (Enteshari & Safavi, 2020). In this study, the qualitative method of root cause analysis (RCA) was used to investigate WRM in the irrigation and drainage network of the Gavshan Dam. Root cause analysis can assist in identifying factors affecting the imbalance between water use and the amount of available water resources, and if addressed to problems, it can improve management strategies to achieve a balance between uses and resources. In general, RCA seeks to find effective solutions to various challenges so that they do not reoccur (Piltch-Loeb et al., 2018). To the best of the authors' knowledge, RCA has not yet been applied to the analysis of socio-hydrological systems, despite its use in other water-related studies such as water supply (Piltch-Loeb et al., 2018), dam construction (Kamalan & Maghanaki, 2020), and other engineering, experimental, and medical studies (Arias Velásquez & Mejía Lara, 2020; Ashena et al., 2021; Doskocil & Lacko, 2019; Duan et al., 2020; Murata, 2021; Zhong et al., 2020).

The water reserves of the Gavshan Dam, which are crucial to food security and agricultural development, are facing water stress that will increase in future decades due to climate change. Some hydrological and human issues that have disrupted the balance between water uses and water resources and created many challenges for the WRM of the Gavshan Dam's irrigation and drainage network include recent droughts and management inefficiency in water planning and monitoring as well as exploitation (Zarafshani et al., 2017). In addition, agriculture is the most important factor influencing the hydrologic condition and scarcity of water in Kermanshah province. Meanwhile, the efficiency of water utilization in the agricultural sector within the Gavshan basin is suboptimal. The general policies of water resources management in the Gavshan basin have been to expand the surface of irrigated lands upstream of the basin (Bilavar Plain), which has increased the demand for water consumption (Zarafshani et al., 2017). Upstream farmers' disregard for channel maintenance and unjust and unauthorized water use have resulted in water scarcity in downstream lands, which is compensated for by groundwater resources. As a result, there has been an increase in soil salinity, leading to a decrease in both the quantity and quality of water downstream in the Miyan Darband Plain (Regional Water Comoani of Kermanshah, 2020). Expanding the cultivated area like a pressure lever leads to overexploitation of surface water and groundwater resources. Excessive abstraction of groundwater resources has reduced their level in the network's southern reaches, causing land subsidence and cracks in water channels (Zarafshani et al., 2017). Furthermore, the water allocated to the Hashilan wetland downstream of the dam was reduced from 2017 to 2021, causing the wetland to dry up and destroying the majority of its plant and animal species (Regional Water Company of Kermanshah, 2020). Simultaneously, as new agricultural lands were incorporated, a portion of the existing agricultural land remained uncultivated. Government support seemed insufficient and sporadic, making it challenging for many farmers to shift from traditional rain-fed practices to irrigated ones, which require additional investments and expertise (Zarafshani et al., 2017). Thus, social changes (e.g., population growth, immigration, rising per capita water consumption, growth of the agricultural sector, improper development of pressurized irrigation systems, and changing the water allocation to an unfair pattern) have affected the dynamics of the hydrological system of the Gavshan Dam. Hence, improving local understanding of the impacts of human societies on water hydrology is essential for regional development and increasing community sensitivity. A deeper understanding of the dynamics of socio-hydrological systems helps policymakers develop effective management plans. Most previous studies (e.g., da Silva & de Souza, 2023; Distefano et al., 2020; Roobavannan et al., 2020) focused solely on social hydrology modeling and theory development. So far, few studies have attempted to operationalize social concepts, particularly socio-hydrological concepts, in WRM. In this study, RCA was used to bridge the gap between the conceptual socio-hydrological frameworks and their practical approaches. A conceptual framework has been developed to capture the socio-hydrologic interaction in the Gavshan basin (Figure 1). This study aimed to identify the causes of the imbalance between water use and water resource availability. It also offers a general overview of the socio-hydrological system for the irrigation and drainage network of the Gavshan Dam. Root cause analysis aids in identifying the causes of the imbalance between water uses and water resource availability and provides a general picture of the socio-hydrological system for the irrigation and drainage network of the Gavshan Dam. Hence, this study attempts to address the following questions: (1) which human factors have affected the physical hydrology of the area, and (2) what were the main factors causing the imbalance between water use and the amount of water resources in the area.

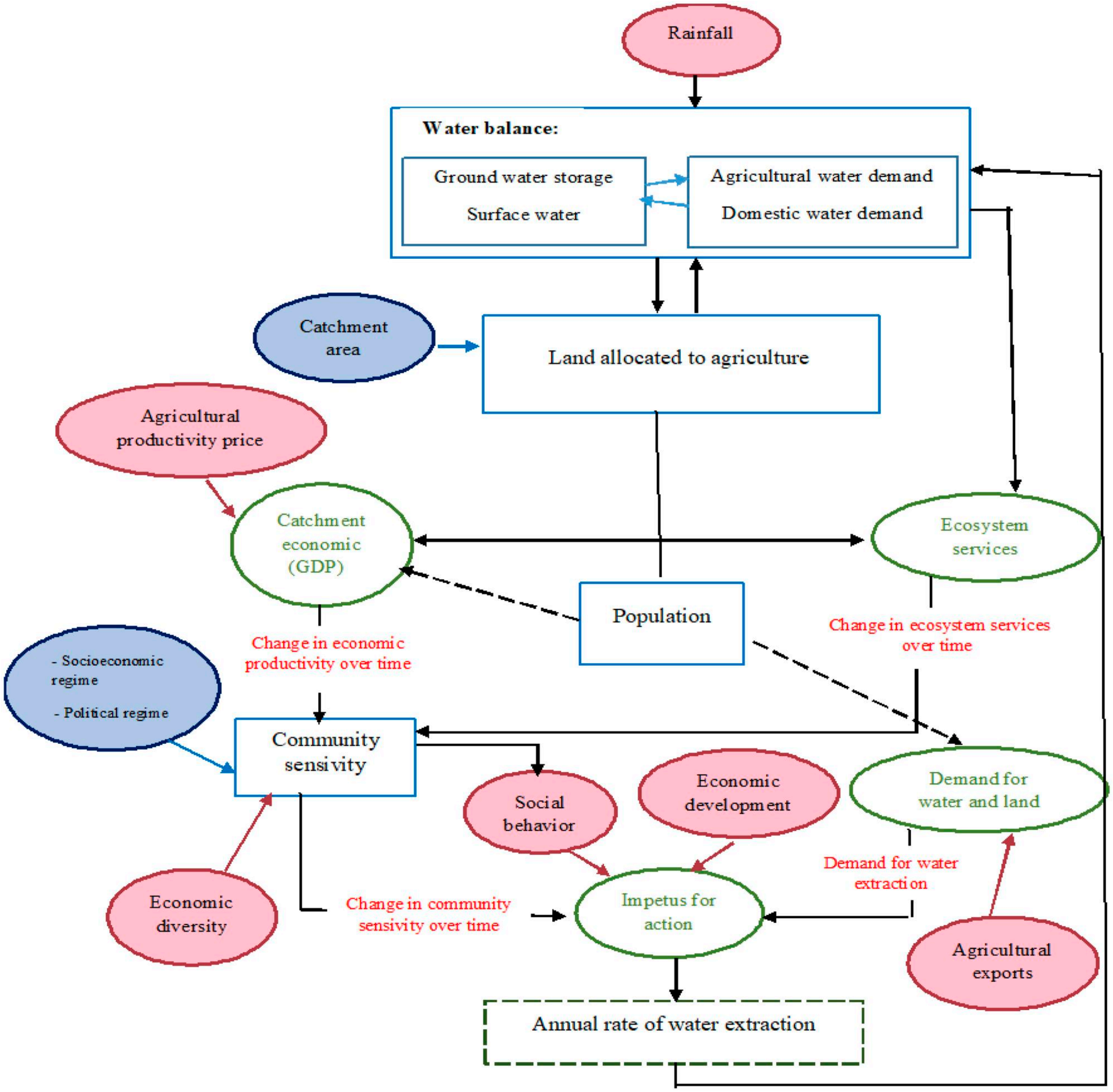

Figure 1. The socio-hydrology conceptual framework adapted for application to the Gavshan catchment. Source: Adapted from Elshafei et al. (2014).

Material and methods

Study site

Gavshan basin is a part of the border watershed of western Iran, which includes three main sources of water (i.e., groundwater, surface, and rainwater sources). According to the Kermanshah Meteorological Organization (2022), over the past 10 years, the average annual rainfall in the Gavshan basin has been 280 mm/year, which has decreased compared with the 30-year average (405 mm/year). Moreover, there are about 11,363 wells for domestic, agricultural, industrial, and service water supply in the Gavshan basin. Meanwhile, over the past 10 years, the groundwater depletion level has decreased by about 18 (m; Regional Water Company of Kermanshah, 2020). Gavshan Dam was built on the Gavshan basin in 2002. The Gavshan Dam project includes a reservoir dam in Kurdistan province, a water transfer tunnel, and irrigation and drainage networks in Kermanshah province. The dam rises 116 (m) above the riverbed and has a crown length of 730 (m). The dam is made of clay sand and has an impermeable clay core (Regional Water Company of Kermanshah, 2020). The volume of the dam storage varies from 60 to 450 Mm^3 depending on precipitation, inflow, river flow, evaporation, stream, etc. The Gavshan Dam feeds from two inputs include surface runoff (from precipitation) and groundwater water (Regional Water Company of Kermanshah, 2020). The dam's construction goals were to harness surface water for the irrigation of approximately 30,650 ha of land in the plains of Bilavar and Miyan Darband, to supply a portion of Kermanshah's drinking water requirement and to generate 9.2 MW of power from the dam (Figure 2). However, in practice, the dam has only been used to irrigate 9,000 ha of farmland in Bilavar (the upstream area), and so far, managing its irrigation and drainage network in Miyan Darband (the downstream area) has failed to effectively deliver water to users and maintain the irrigation network. Drought and the insufficient rainfall over the past decade,coupled with inadequate

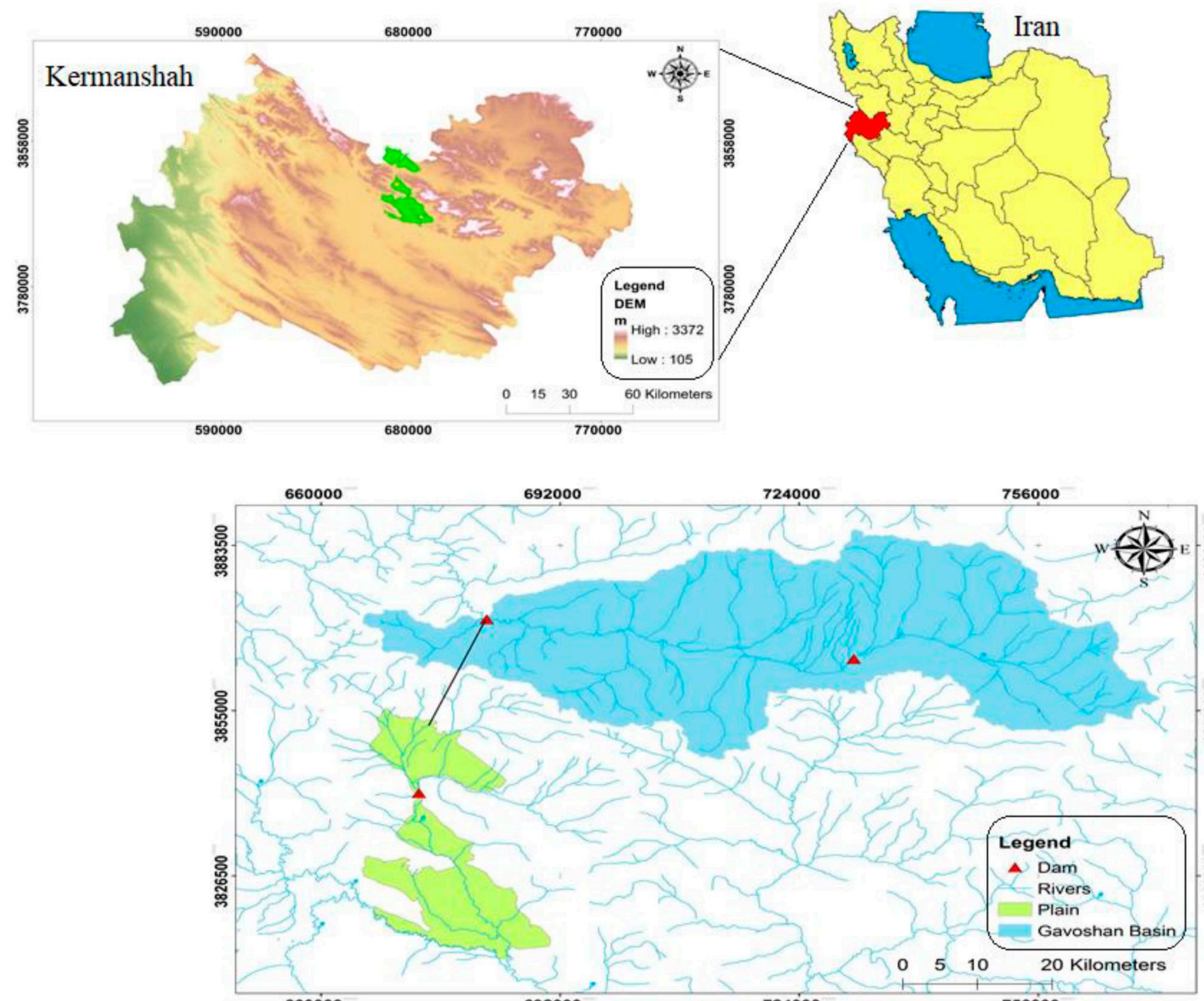

Figure 2. The Gavshan Dam basin. Source: Regional Water Company of Kermanshah (2020).

government funding for the power plant's establishment, have prevented the Gavshan Dam construction from meeting its multipurpose utilization. Therefore, one of the key features of the Gavshan Dam is the supply of agricultural water to 9,000 ha of Bilevar Plain. In the Gavshan basin, agriculture serves as the primary occupation of the residents and constitutes the foundation of the local rural economy. Agrarian practices in the Gavshan basin have a long history dating back to thousands of years ago. One important aspect of this region's agrarian practices is the qanat system, an ancient underground irrigation system that was developed by the Persians. These qanats helped transfer water to cultivated areas and allowed for the cultivation of crops such as wheat and barley in this area. Meanwhile, only 12% of the total land area is irrigated and 87% of the total land is devoted to dryland farming.

In the Gavshan basin, run-off has decreased due to lack of precipitation in the last decade. Furthermore, a significant portion of the water that flows through the irrigation channels of the Gavshan Dam is not restored. Groundwater tables, on the other hand, are depleting at a faster rate due to overabstraction for irrigation and an increased rate of evapotranspiration. Therefore, the decision to select this region is the low performance of the Gavshan irrigation network.

Methodology

Most activities encounter issues whose direct and indirect causes must be investigated (Suárez-Barraza & Rodríguez-González, 2019). This study first looked into the causes of the imbalance between water consumption and water resources, and then it identified the underlying components by determining the root causes. The causes of any problem are classified into three types: potential causes, direct causes, and root causes. The visible evidence of an incident is known as a potential cause. Any potential or real situation can cause problems. Direct causes (proximate causes) explicitly manifest the potential or actual situation. A direct cause directly results in the occurrence of an incident and, if eliminated or modified, it would prevent the undesired outcome (Holifahtus Sakdiyah et al., 2022). Finally, root causes are one of the multiple factors (i.e., events, conditions, or organizational factors) that create the direct cause (proximate causes) and the subsequent undesired outcome. Typically, several root causes result in undesired outcomes. Root cause analysis seeks the root cause of an incident or issue rather than simply addressing the proximate cause (Suárez-Barraza & Rodríguez-González, 2019). According to the reports of the Gavshan Dam's irrigation and drainage network management, there is no balance between water resources and water consumption (Regional Water Company of Kermanshah, 2020). This study outlines the following steps to identify the causes of the imbalance between water consumption and water resources (Figure 2).

Step 1: Identifying the potential causes

Some semistructured interviews were done in two phases from September 2020 to February 2021. First, 87 network user farmers from 41 villages were interviewed using socio-hydrology criteria to gain a clear understanding of the network's status and problems. The sample size was collected using the purposeful snowball technique. The interviews began with topics drawn from the socio-hydrology literature and an initial visit to the dam and the irrigation network. Then an attempt was made to detect the causes of the Gavshan Dam's problems.

From the hydrological point of view, factors such as precipitation, volume of surface water and underground water, volume of the dam, and the methods of water allocation among farmers were considered. Moreover, the hydrological interviews focused on access to the water of the dam, number of farms that use the network, and number of seasonal and permanent rivers, wells, qanats, and springs that could be used to supply irrigation water. From the social aspect, the components of population, social participation, social responsibility, employment, government assistance, investments and social knowledge related to agriculture, and ecosystem services were considered. In addition, social questions on the development of residential areas and communities around the dam, household livelihood aspects (e.g., income, expenditure, and employment), and future perspectives and problem-solving approaches were woven into the interviews. Water access questions included irrigation turns, water allocation strategies, the maintenance of the irrigation channels and equipment, water pricing, and unauthorized withdrawal. A few questions on agricultural operations, such as the agricultural and horticultural cultivation area, animal farm areas, agricultural practices used at each crop farm, cultivation area, crop pattern, and yield, were also integrated throughout the interviews. During the interviews, the study attempted to develop trust so that the interviewees could respond to provide confidential information on the unauthorized use of water through unauthorized wells, the use of extra sprinkles, and unauthorized water withdrawal from the canals. The interviews were conducted face-to-face. To establish trust, the interviewee's name was not requested, and the details of responses were documented. The triangulation technique was used to test the validity of this qualitative research. Patton (1999) identified four types of triangulations: (a) method triangulation, (b) investigator triangulation, (c) theory triangulation, and (d) data source triangulation. In this study, data triangulation was used. In data source triangulation, researchers use different methods of data collection (qualitative and quantitative methods) to validate the results of their study (Patton, 1999). Data triangulation via the convergence of information from various interviews results in a more comprehensive understanding of human–water systems. The data were analyzed using a conventional approach to qualitative content analysis (Zarafshani et al., 2017) with two stages of open and axial coding in the Maxqda software version 2020. The texts were labeled and classified using open coding. The relationships between categories and subcategories were addressed in axial coding. Following qualitative content analysis, 299 potential causes were identified. Following the identification of causes, an Ishikawa diagram was created to better understand the relationships of the detected direct causes. The Ishikawa diagram (also known as the fishbone diagram), cause-and-effect diagram, tree diagram, or river diagram display qualitative features and causal causes. The mental maps based on the fishbone technique were created using the X-Mind software package.

Step 2: Identifying the direct causes

To collect data on the direct causes of the problem, semistructured interviews were conducted by the RCA team. The RCA team consisted of eight experts and managers from the regional water company, agriculture jihad organization, environment department, and academia who were well versed in problems of the Gavshan basin. Direct causes of the problem were investigated using the five whys technique, which was deemed the most important and efficient tool, as well as Pareto analysis (Doskocil & Lacko, 2019). Researchers began to ask several why questions to identify the second- and third-level causes in a deductive manner to arrive at the root cause of the problem (Holifahtus Sakdiyah et al., 2022). Based on the 5 Whys technique, 30 direct causes were identified.

Step 3: Identifying the root causes

After conducting interviews and identifying the potential and direct causes of the problem, the researchers reconvened with the RCA group participants to present them with the Ishikawa diagram and a list of all direct causes. The RCA group identified and ranked the root causes using the gravity, urgency, and tendency (GUT) decision matrix, with a score of 1 to 5. It was judged that any cause with a higher number is more important to the problem; therefore, solving it is a priority (Doskocil & Lacko, 2019). The GUT matrix scores range from 1 to 5:

1. This is not an important or urgent cause and ignoring it will not worsen the problem over time.
2. This is a marginally important and urgent cause that will only exacerbate the problem in the long run.
3. This is an important and urgent cause that will exacerbate the problem in the medium term.
4. This is a critical and urgent cause that exacerbates the problem in a short time.
5. This is an extremely important and urgent cause that, if not addressed immediately, it will rapidly worsen the situation.

The Pareto diagram was then used to comprehend the prioritization of the root causes. A Pareto chart is a histogram that shows where and on what causes decision-makers should focus their efforts by categorizing data and supporting prioritization (Doskocil & Lacko, 2019). Therefore, the Pareto chart is an important management decision-making tool. The research procedure is depicted in Figure 3.

Results

Socio-demografic variables

Table 1 shows the demographic features of farmers in this study. The average age of the farmers was 51.45 years. All respondents were men, and 55.70% of the farmers had less than a high school degree, 35.44% had a high school diploma, and 8.86% had higher education. The average area under cultivation was about 2.5 ha. The average agricultural experience of the farmers was 28.60 years, revealing the experience of the farmers in the survey sample. The main crops cultivated were wheat, barley, canola, and maize.

First phase: Identifying the direct causes of water management inefficiency

Interviews with farmers revealed that irrigation network issues are caused by an imbalance between water uses and water

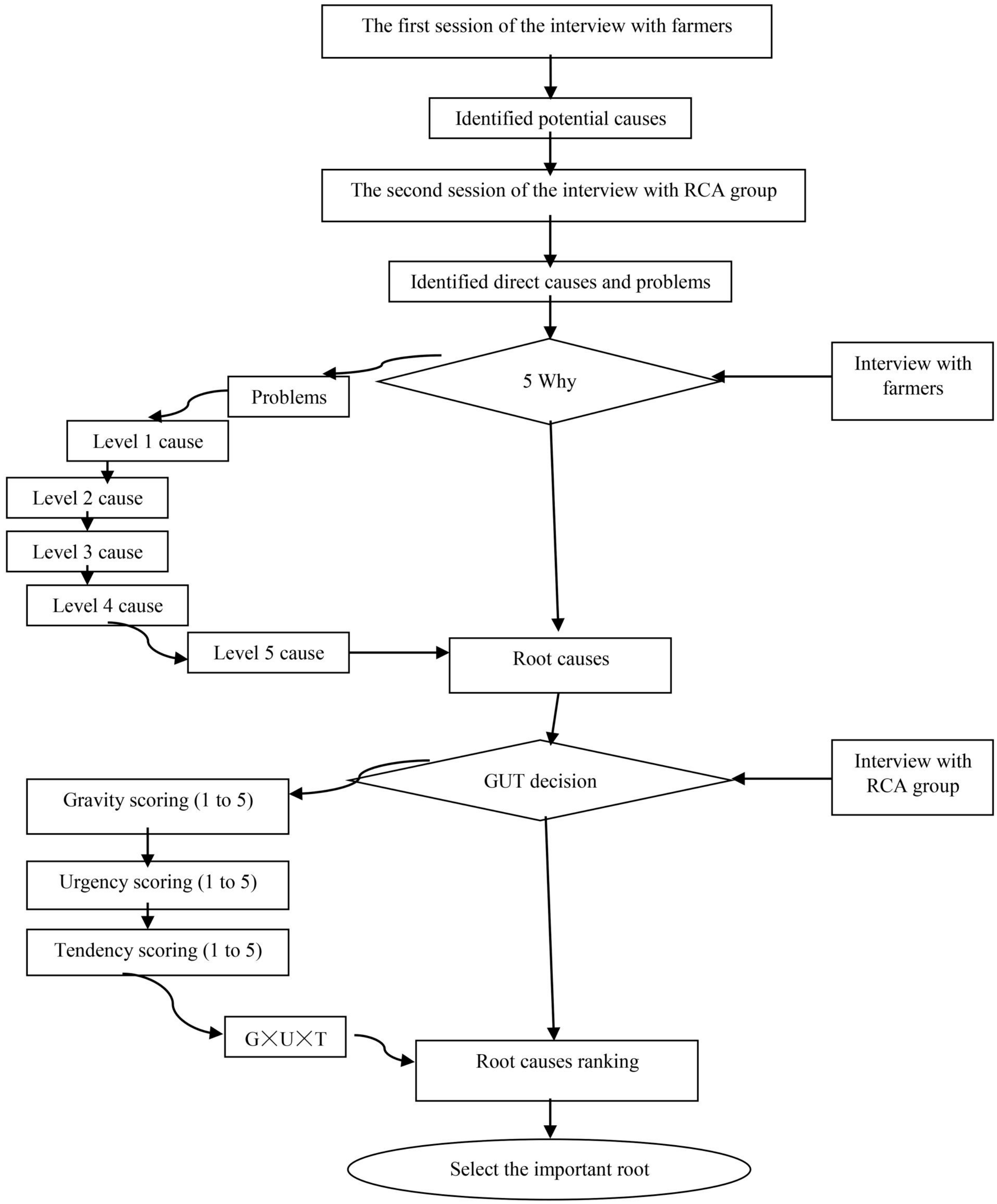

Figure 3. The research process of this study.

resources as well as water management inefficiency. In other words, first-level causes were already identified. Following a qualitative content analysis of the interview data, 30 initial codes were inferred and displayed within seven categories, along with the frequencies and percentages of codes received from the interviewees (Table 2).

According to the findings, the direct causes of the Gavshan Dam's problems were classified into seven categories: hydrological, population dynamics, economic, ecosystem service, community sensitivity, behavioral action, and political-institutional. The most important and fundamental causes of water management inefficiency included the categories ineffective administrative structure (political-institutional; gaining 48.49% of the total scores), weak behavioral action (21.41%), and ecosystem services (11.01%). Although the economy, hydrology, social dynamics, and community sensitivity components were directly influential in creating the problem, their contributions were limited to only 9.06%, 4.68%, 4.01%, and 1.34%, respectively. Assigning the lowest percentage to community sensitivity demonstrates that the socio-hydrological system in the Gavshan Basin is not fully

Table 1. Socio-demographic variables associated with farmers.

Variable	Category		
Age (average)	Years 51.45		
Education (percentage)	8 years of education 55.70	12 years of education 35.44	Higher education 8.86
Cultivated area (average)	Ha 2.5		
Agricultural experience (years)	Years 28.60		
Main crop	Wheat Barley Canola Maize		

Source: Research findings.

understood and that the allocation of more water for consumption has created a large gap between water resources and water uses.

In addition, among the 30 first-level causes, the most effective direct causes of the problem were found to be "unauthorized exploitation of the network," "monitoring-managerial weaknesses of the organizations in charge," "nonparticipation in contract making," "land defragmentation," "lack of just allocation of water among users," "lack of group work morale in water distribution," and "land waterlogging" (Table 2). The RCA group contended that although the other causes were effective in water management, they played a minor role in causing the target problem compared with these six problems. After identifying the direct causes of the problem, tools such as the fishbone diagram or the Ishikawa diagram were used to illustrate the root causes of the problems. The fishbone diagram shows cause-and-effect relationships related to socio-hydrology and water management (Figure 4).

According to Figure 4, the main factors in this causal diagram are ineffective administrative structure, economic catchment, population dynamics, weak community sensitivity, weak behavioral action, ecosystem services, and hydrological causes. The factors mentioned are the direct causes of the imbalance between water resources and consumption. Understanding the direct causes of a problem is essential to ensuring that all conditions are addressed when determining the root cause. However, direct causes do not necessarily indicate the root cause or main causes of an issue. Direct causes are only the factors that contribute to the exacerbation of a problem or issue. Hence, in the second phase, the root causes of inappropriate management were investigated to identify the main reason for water management inefficiency. Root causes are seen as the underlying or deeper issues that are the primary cause of the problem. In other words, root causes are the same factors that if removed or corrected, not only will other direct causes be corrected but also can help solve the main problems for water management.

Second phase: Identifying the root causes of water management inefficiency by the GUT decision matrix

Following the investigation of the direct causes, the RCA group identified 16 root causes using the 5 Whys technique. The 16 identified causes are, in fact, mismanagement factors that contribute to the imbalance between water use and water resources. Although the intensity, urgency, and tendency of each of these causes are varied (Table 3), eliminating or correcting one of them would not only modify the other causes but also could be useful for management strategies and contribute to managing optimal water use in regional farming.

According to the results, "improper cultivation and irrigation management" was placed on the top priority of problem-solving with a score of 125, "lack of implementation of crop rotation" (score = 100) was placed on the second priority, and "lack of management at the basin level" (score = 80) was placed on the third priority. Therefore, the participants argued that these causes have crucial importance in achieving optimal water use management in agriculture. They are so important that if they are not solved or modified immediately, they will exacerbate the problem immediately or in the short run (Table 3). Figure 5 was created to show the relationships of the root causes. The utility of the socio-hydrological approach in this study is to improve agricultural water management at the levels of local farmer operations and political-institutional management issues. In addition, the socio-hydrological approach in this study considered the effects of social change (e.g., population growth, immigration, rising per capita water consumption, growth of the agricultural sector, improper development of pressurized irrigation systems, and water allocation) on the hydrological system of the Gavshan Dam.

As shown in Figure 5, the RCA group classified the root causes of the problem into five major categories: low water productivity in agriculture, lack of economic justification of some agricultural products, management weakness in crop yield, social unsustainability, and lack of secondary employment in agriculture. Also, some farmers' discontent with inadequate governmental support for the development and structure of agricultural activities and the incurrence of high costs for use and maintenance of the irrigation network has limited the number of main stakeholders and has motivated unauthorized water exploitation (Figure 5). Although a fishbone diagram can represent an analysis of the root cause of problems, it cannot facilitate the analysis of the root cause correlation between the categories. Finally, Pareto analysis was used to classify the root causes (Figure 6).

Pareto analysis

In the next step, the results were displayed as a Pareto chart to allow for comparing distribution and better understanding of the root causes selected by the GUT criteria (Figure 6). Based on the Pareto chart, the important root causes with the highest effectiveness in the problem are determined after the breakdown points (i.e., where the cumulative frequency percentage points on the chart start to flatten) are specified. Based on this chart, 60% of the problems of the irrigation network that cause the imbalance between water use and water resources are accounted for by five main root causes, i.e., (i) improper cultivation and irrigation management, (ii) lack of implementation of crop rotation, (iii) lack of management at the basin level, (iv)

Table 2. Frequency of codes referred to the concepts of the direct causes of the problem (water management inefficiency).

Factor	Percentage of each factor	Code	Direct causes	Frequency	Percentage
Hydrological factors	4.68	HF1	Absence of precipitation	1, 3, 4, 7, 8, 9, 47	2.34
		HF2	Groundwater level decline	1, 3, 6	1
		HF3	Surface water quality deterioration	28, 32, 50, 51	1.34
Population dynamics	4.01	PD	Migration	2, 3, 8, 12, 15, 25, 35, 39, 40, 41, 48, 52	4.01
Basin economy	9.06	BE1	Low productivity of products	4, 5, 6, 7, 12, 14, 15, 25, 33, 34	3.34
		BE2	Increases in input price	1, 3, 4, 7, 8, 14, 37	2.34
		BE3	Reducing the income of farmers	6, 7, 8, 37	1. 38
		BE4	Inadequate capital to protect the irrigation network	1, 17, 28	1
		BE5	Inappropriate water pricing	1, 3, 44	1
Ecosystem services	11.01	ES1	Decreasing the quality of the agricultural layer of the land	3, 10, 24	1
		ES2	Soil erosion	3, 4, 10, 12, 16, 21, 24, 48	2.67
		ES3	Drying of the Hashilan wetland	3, 5, 10	1
		ES4	Reducing the diversity of plant and animal species	52, 53, 54	1
		ES5	Land water logging	1, 3, 4, 7, 9, 10, 11, 12, 14, 43, 44, 47, 48, 49, 50, 54	5.34[a]
Community sensitivity	1.34	CS1	Overirrigation and insensitivity of society to water shortage	10, 13	0.67
		CS2	Lack of water crisis awareness	5, 8	0.67
Behavioral actions	21.41	BA1	Nonparticipation in contract-making	3, 5, 6, 7, 9, 13, 22, 25, 28, 29, 30, 33, 35, 36, 37, 40, 42, 43, 45, 48, 50, 52, 53	7.69[a]
		BA2	Passivism of water users associations	3, 5, 17, 46, 47, 50	2.01
		BA3	Excessive water consumption	1, 6, 7, 8, 10, 12, 16, 19, 20, 22, 25, 26	4.01
		BA4	Farmers' irresponsibility	3, 4, 17, 19, 33, 54	2.01
		BA5	Lack of group work morale for water distribution	3, 4, 8, 12, 15, 18, 19, 20, 24, 25, 26, 29, 30, 37, 39, 41, 46	5.69[a]
Political-institutional	48.49	PI1	Defragmented lands	1, 3, 5, 7, 8, 9, 10, 12, 15, 20, 25, 26, 35, 37, 41, 48, 49, 50, 54	6.36[a]
		PI2	Use of equipment and low-quality parts in the networks	2, 4, 5, 8, 15, 20	2.01
		PI3	Unauthorized withdrawal of water	1, 3, 4, 6, 10, 12, 17, 19, 22, 24, 25, 28, 29, 30, 31, 33, 34, 36, 37, 39, 41, 43, 45, 46, 48, 49, 52, 53	9.37[a]
		PI4	Monitoring-managerial weaknesses of the organizations in charge	2, 3, 4, 5, 8, 9, 20, 26, 27, 29, 31, 35, 36, 40, 41, 45, 46, 47, 48, 49, 51, 52, 54	8.02[a]
		PI5	The delegation of the network's management to nonproductive capital companies	12, 16, 17, 22, 24, 36, 49, 51, 53, 54	3.34
		PI6	Lack of cooperation and awareness among organizations	8, 9, 12, 33, 35, 46, 48, 49, 50, 51, 52, 53, 54	4.35
		PI7	Poor governmental support of the network maintenance	2, 4, 5, 12, 13, 17, 35, 38, 40, 41, 43, 44, 48, 50	4.68
		PI8	Lack of just allocation of water among users	3, 5, 7, 9, 10, 12, 15, 16, 19, 24, 25, 32, 33, 34, 35, 36, 39, 41, 46	6.35[a]
		PI9	Delays in water delivery	3, 4, 6, 8, 18, 22, 34, 39, 43, 46, 47, 48	4.01

Source: Research findings.
[a] > 5%.

water stress caused by power outages, and (v) decline in crop prices (Figure 6).

Discussion

This research presents an RCA method for water resources management based on the combination of Fishbone analysis, GUT matrix, and Pareto analysis. The results show that this combined method could identify the root causes of water management challenges and discover opportunities for improved management. The effectiveness of this methodology was demonstrated through a case study on the Gavshan Dam, showing that the social factor is critical in water management. These findings are consistent with the findings of Konar et al. (2019), in which water management is a point at which the human and water systems converge and the borders between the human, social, and natural systems fade. The results of this study also show that a more detailed understanding of the functions of socio-hydrological systems requires in-depth field investigations.

In field research, the use of qualitative methods such as RCA can fill the wide gap between the knowledge bases and methodologies of hydrological and social sciences. The results of this

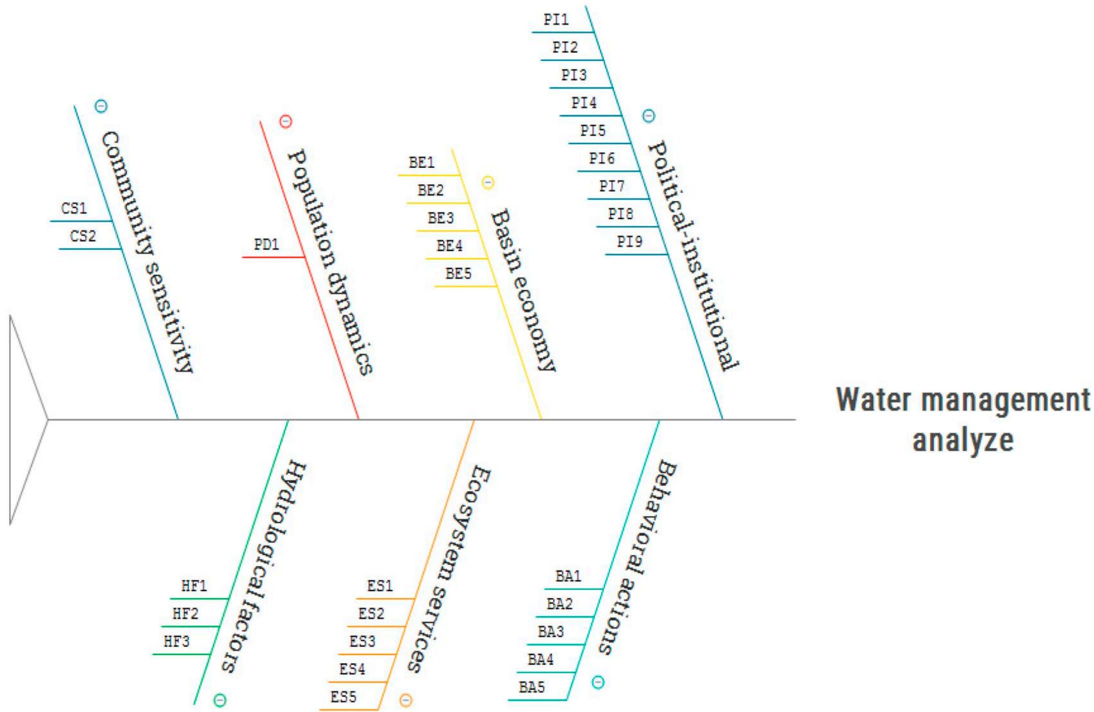

Figure 4. Fishbone analysis to identify the direct causes of water management inefficiency (for the correspondence between the direct causes assigned to the problem see Table 2). Source: research findings.

Table 3. Assessing the gravity, urgency, and tendency of the root causes of the water management inefficiency.

Root causes	Code	Gravity	Urgency	Tendency	Assessment G U T	Ranking
Improper cultivation and irrigation management	RC1	5	5	5	125	1
Lack of implementation of crop rotation	RC2	5	4	5	100	2
Lack of management at the basin level	RC3	4	5	5	80	3
Water stress caused by power outages	RC4	5	5	3	75	4
The decline in crop prices	RC5	4	4	4	64	5
Disruption in market balance	RC6	4	5	2	40	6
Nonuse of new agricultural patterns (greenhouse)	RC7	4	3	3	36	7
Increase in smallholding/decline in cultivation area	RC8	4	2	4	32	8
Farmers' noncooperation in signing water tariff contracts	RC9	5	3	2	30	9
Farmers' low responsibility in irrigation network maintenance	RC10	3	3	3	27	10
Lack of sustainable self-sufficiency	RC11	5	5	1	25	11
Farmers' noncooperation for participatory irrigation	RC12	5	2	2	20	12
Poor life quality in rural communities	RC13	3	2	3	18	13
Nondevelopment of secondary agricultural employments	RC14	4	4	1	16	14
The increase in the unemployment rate in rural communities	RC15	3	5	1	15	15
The increase in rural people's migration to urban areas	RC16	4	3	1	12	16

Source: Research findings.

study showed that RCA illuminates information on various socio-hydrological system-level interactions that can aid in decision-making. This finding is in line with Kamalan & Maghanaki's (2020) findings, that RCA analysis identifies which areas have potential problems and should be addressed. Furthermore, in conjunction with other tools such as fishbone and Pareto analyses and GUT matrix, RCA can overcome limitations and depict important interrelationships among root causes to help make decisions regarding socio-hydrology systems. Based on the findings of this study, the most important causes of water management inefficiency, which cause an imbalance between water use and water resources, were water management inefficiency, weak behavioral action, and weak ecosystem services. Enteshari et al. (2020) and Roobavannan et al. (2020) have also pointed out that water management inefficiency causes have led to excessive water allocation and unauthorized withdrawal.

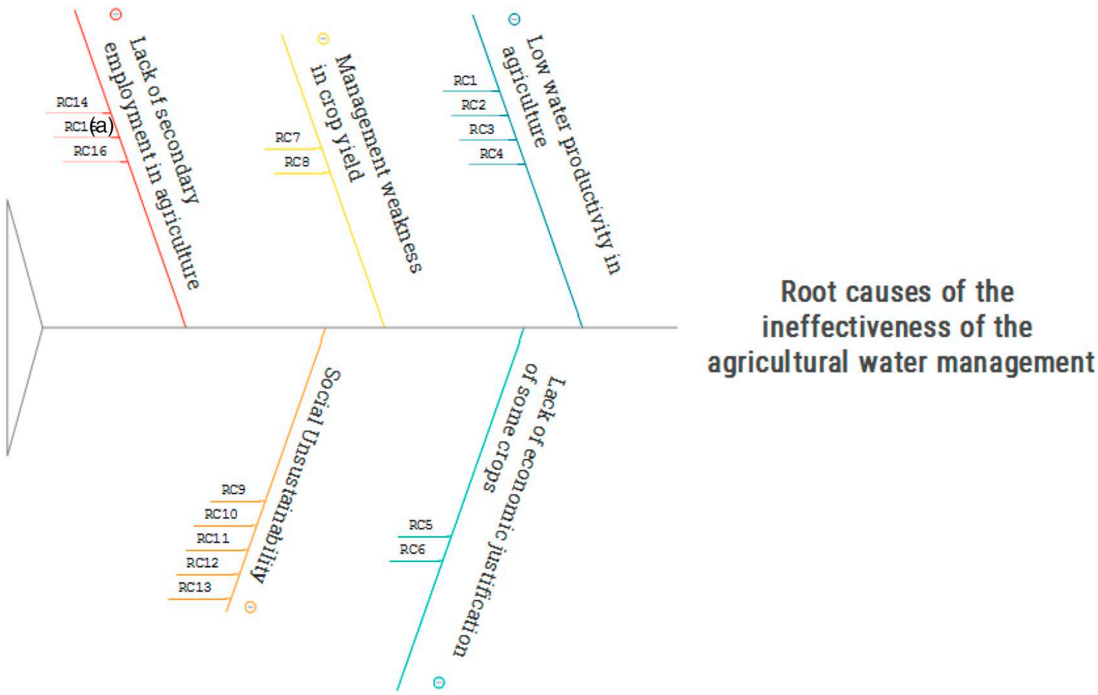

Figure 5. Fishbone analysis to identify the root causes of the water management inefficiency (for the correspondence between the root causes assigned to the problem see Table 3). Source: research findings.

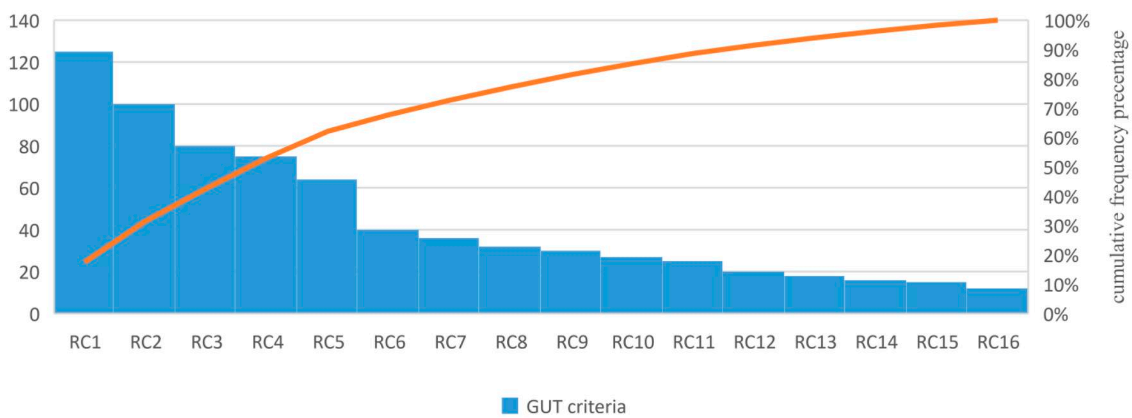

Figure 6. Descending ranking of the root causes of the problem (Pareto diagram).

The results showed that the hydrological component is a direct cause of the imbalance between water availability and water consumption in regional farming. In this respect, Iwanaga et al. (2020) concluded that water resources have traditionally been overallocated to farming goals and that there is a chance of a drier climate in the future. This means that the balance of water resources between competing demands and resources will be more difficult to attain.

Our results indicate that the birth rate was fixed in the villages served by the Gavshan Dam, and population dynamics have caused an increase in the per capita consumption of water in the Gavshan basin. The main population dynamic was migration from the two provinces of Kermanshah and Kordestan (Statistical Center of Iran, 2021) to the Gavshan basin. The Gavshan basin is an agricultural area to which people migrate to gain economic profit. Gunda et al. (2018) also stated that migration to a location near a water basin aggravates water scarcity. Based on Enteshari & Safavi's (2020) findings, the per capita renewable water is reduced to 600 million m^3 per person per year. It is notable that the economic cycle of the residents in the plain of Bilevar is supplied by agriculture. Since 2013, the Gavshan Dam has controlled the water supply system for irrigation and domestic use. However, because of the abundance of water, farmers have not felt the need to improve the efficiency of the irrigation system. Such a result has been observed in a study of the Tagus River basin in Spain (Dionisio Pérez-Blanco et al., 2020). This result is in line with the findings of Pouladi et al. (2019). They found that farmers have been led towards more profitable agronomic patterns with minimum cost and more environmentally conservative practices due to undesirable financial conditions.

The water system serves as the crucial link between society and the environment. Despite the importance of water to the environment, humans are changing water resources by dam construction on rivers and extracting surface water and groundwater, thereby affecting the water cycle process. In addition, interactions between humans and water bodies affect the various benefits that ecosystems provide to society. For example, lack of drainage systems in the fields of the Gavshan basin has led to the flow of mud and accumulation of mud in the downstream lands. Over time, this has caused dissatisfaction among farmers and has created social tensions in the region. Because some users close the valves of sprinkler pipelines and use flood irrigation to speed up the watering process, frequent floods and increased surface run-off during irrigation become major threats to land erosion and loss of quality in the agronomic layer of the soil and ecosystem service reduction. In some cases, flood irrigation causes waterlogging in the lands located downstream and reduces crop yields. Ogilvie et al. (2019) asserted that the silt flowing from upstream flood irrigation caused downstream dam lands to reduce farming capacity. In this study, the triangulation method helped the understanding of socio-hydrological systems (e.g., who shares the water pumps of irrigation networks, did the government assist, what happened to the water user associations, conflicts, etc.). According to the results, 20% of the water pumps were out of order due to lack of regular maintenance. The absence of spare parts and difficulties to cover repair costs led to extended irrigation periods before pumps were repaired. Another cause of the ecosystem service reduction of the Gavshan Dam is the drying up of the Hashilan wetland downstream. The unauthorized use of the wetland's water by local farmers and the non-transfer of water from the Gavshan Dam to the wetland have reduced the wetland's inflow and the chance of enjoying its ecosystem services. The decline in ecosystem services can influence farming activities by increasing community sensitivity to environmental degradation. These findings complement prior findings (Boruff et al., 2018; Roobavannan et al., 2017) that preserving water resources necessitates a socio-hydrology system understanding to determine how the reduction in ecosystem services presents itself as water supply restrictions. Based on the results, the behavior and response of human communities to water management is referred to as community sensitivity in socio-hydrological studies (Mostert, 2018). The results show a lack of understanding of community sensitivity in the studied region. For example, one farmer said "The digging of unauthorized wells has been increased in recent years so that the water of the Hashilan wetland is used for farm irrigation by using electrical pumps. The over-exploitation of the wetland caused its drying in the summer of 2021. I have never heard that the Wetland has ever been dry." Also, a water expert noted "The severe depletion of groundwater resources has resulted in land subsidence and destruction of water-transfer channels." A similar study conducted by Mostert (2018) showed that community sensitivity had not yet been understood in the basin of the Dommel River, the Netherlands. Based on the findings of this study, behavioral actions are mistaken for the degradation of ecosystem services due to the very poor understanding of human–water coevolution. Behavioral actions are human responses to changes in community sensitivity (Kumar et al., 2020). One reason behind inefficient water use is human behavior. The results of this study showed that farmers' behavior did not consider conservation actions in water consumption, i.e., water consumption was at higher levels. The nonparticipation of institutional stakeholders (i.e., organizations and water managers), the passivism of water user associations, excessive water consumption, farmers' irresponsibility, and lack of group work motivation for water distribution are all symptoms of destructive behavior. As asserted by Dadvar et al. (2021), water management systems should include individual measurements to allow stakeholders to monitor the amount and expense of their water use. Furthermore, linking knowledge of socio-hydrology with stakeholder participation would contribute to conservation actions in water consumption.

Based on the findings of this study, the most important direct causes for the inefficiency of the current administrative structure include lack of cooperation and awareness among organizations, monitoring and managerial weaknesses of the organizations in charge, and poor governmental support of network maintenance. Enteshari et al. (2020) also support this claim. They mentioned that enhancing manager understanding of policies and management approaches can lead to an efficient method of sustainable water management. As asserted by O'Keeffe et al. (2018), the behavior of stockholders and the managers of water offices and farm practices are vital for policy-making for the direct use of water, and these factors are operational tools to achieve water security and livelihood.

The results show that the direct causes of inappropriate water management include hydrological factors, population dynamics, basin economy, ecosystem services, community sensitivity, behavioral actions, and political-institutional actions. These causes are the factors that contribute to the exacerbation of the imbalance between water users and water resources. Hence, the root causes of inappropriate management were investigated through the 5 Whys technique and the GUT matrix. Based on the results, the root causes of the problems were categorized into five major classes: low water productivity, lack of economic justification of some crops, management weakness, social unsustainability, and lack of secondary employment. These five root causes are the same factors of inappropriate water management that if removed or corrected, not only will direct causes be corrected but also can help solve the problems of water management. However, each root cause is different in gravity, urgency, and tendency (Table 3). Achieving the best water usage practices in agriculture requires addressing the underlying causes of the issues. The first rank of improper cultivation and irrigation management in Pareto analysis shows the significance of this factor in water management because time management of cultivation and irrigation is very important for crop yields. Because the dominant crops are wheat and canola in the study site, if irrigation timing is not managed properly, crop yields will severely decline. Another root cause is the lack of the implementation of crop rotation. Local farmers only cultivate wheat due to the decline in the water reserves of the Gavshan Dam. However, continuous cultivation of a crop in a single parcel of land not only reduces its yield but also causes soil erosion, expansion of pests and diseases, and wastage of capital. Interviews show that the activity of local management institutions in the Gavshan region has been very weak in promoting the community sensitivity towards ecosystem conservation. Moreover, this observation underscores the population dynamic and future climate changes and highlights that climate uncertainty must be incorporated into water resource management policy planning. Implementing educational programs to increase awareness about ecosystem services helps to develop more effective strategies for planning processes and enhancing human well-being. Attention to ecosystem services in the allocation of water resources between upstream and downstream is intricately intertwined with sustainable water management. When allocating water resources between upstream and downstream, it is crucial to emphasize effective accountability and equitable distribution of benefits. These practices play a pivotal role in bolstering public willingness to engage in ecosystem conservation efforts and enhancing community sensitivity.

The qualitative method is flexible and can provide significantly more leverage for policy-making and management

(Mostert, 2018; Ogilvie et al., 2019). Hence, some researchers (e.g., Botai et al., 2022; May, 2021; Mostert, 2018; Ogilvie et al., 2019; Pham et al., 2022) investigated social hydrological research with qualitative methods. In this study, the results of the RCA methodology demonstrated that some of the social components (e.g., employment, water allocation, and social participation and responsibility) that might have been considered as marginal in previous studies (e.g., Albertini et al., 2020; Enteshari et al., 2020) played an important role in the socio-hydrology system of the Gavshan basin. According to the interviews, the effectiveness of water consumption in the agricultural sector in the Gavshan basin is low. The agricultural sector, which is the largest consumer of water, with an average withdrawal of about 90% over the past decades, has also undergone changes over time (Regional Water Company of Kermanshah, 2020). Government assistance appears to have been too limited for many farmers to make the transition from traditional rain-fed activities to irrigated activities, which demand additional investments and knowledge. In the face of ongoing global challenges such as climate change, urbanization, and disparities, the need to comprehend and assess socio-hydrological systems becomes progressively crucial in directing policies and methodologies for fostering a more equitable and robust world. In this regard, the RCA approach attempts to develop social dimensions in the socio-hydrological systems.

Based on the results, interviews indicate that local management institutions in this region are not meeting local needs, and other management methods are needed to improve social behavior. This observation underscores the population dynamic and future climate changes and highlights that climate uncertainty must be incorporated into water resource management policy planning. Implementing educational programs to increase awareness about ecosystem services helps to develop more effective strategies for planning processes and enhancing human well-being. Attention to ecosystem services in the allocation of water resources between upstream and downstream is intricately intertwined with sustainable water management. When allocating water resources between upstream and downstream, it is crucial to emphasize effective accountability and equitable distribution of benefits. These practices play a pivotal role in bolstering public willingness to engage in ecosystem conservation efforts and enhancing community sensitivity.

Conclusion

The socio-hydrology framework supports water resources management, which provides the ability to explain the interactions of water and humans. Socio-hydrology helps water resource managers to identify the future consequences of current decisions and integrate current decisions to achieve optimal results in strategic decisions such as balancing water uses and water resources. Yet, given the complexity of human–water issues, developing an agenda for socio-hydrology is critical. Despite their philosophical differences, hydrology and social sciences have frequently overlapped in coupled human–water systems. Within this context, this study helps to develop the knowledge of social variables in socio-hydrology research. The results showed that RCA could provide an accurate picture of complex human–water problems by identifying the components influencing water resources and uses. Furthermore, the results showed that human–water coevolution has not been fully understood in the studied basin and that the policy of the allocation of more water for consumption has created a huge gap between water resources and water uses. This result reveals how ecosystem services are affected by community sensitivity and political-institutional decisions. The results show that RCA, as a coherent approach based on cause and effect analysis, fills the gap between political-institutional decisions. According to the findings, the interactions between human actions and water cycle dynamics, as well as the evolution of human norms/values about water management, are causing a variety of emergent problems. These issues necessitate a broadening of hydrologic science. Conceptualizing water challenges revealed by this study provides useful insights to help water managers better understand the causes of the social context problems in socio-hydrology systems. This study may have overlooked the role of other causes in predicting socio-hydrology systems. Therefore, future studies could explore additional social-cultural factors that play a role in understanding the impacts on socio-hydrological systems. In addition, future social hydrology research can address the political-cultural dimensions and the short-term and long-term consequences of changes in water governance.

Implications and recommendations

This study demonstrated the practical significance of the socio-hydrology perspective. According to the socio-hydrological perspective, the most important factors in achieving efficient water management are considering crop yield, farmer revenue, cultivation area, employment, and social sustainability in water management. Agricultural policy-makers and water managers can use social hydrology to identify the future consequences of current decisions and integrate current decisions to achieve optimal results in strategic decisions such as balancing water uses and water resources. To achieve a balance between water uses and water resources, it should be noted that water consumption is not determined by the amount of available water; rather, economic, political, cultural, and social incentives shape water consumption patterns. Investment in the diversification of economic activity helps to shift from agricultural to nonagricultural sectors or higher productivity activities, as well as providing equitable growth and development. From a practical perspective, the insights on social challenges and perception of human–water systems revealed by this study can help the designers focus on the fundamental causes, identify potential opportunities for policy, and implement sustainable water management strategies. Further, some practical suggestions, including rewording water distribution rules and investing in water-saving technologies, are necessary to improve water management.

This research indicated that the RCA technique could identify human–water system challenges and improve water management. Hence, future research focusing on socio-hydrology systems can adopt qualitative techniques in their projects and deploy other components such as resilience to climate change and food security. However, the study had several limitations that should be considered in future research. The results show stakeholders' perceptions, but they could be subjected to field trials which were physically and financially beyond the scope of the research. This study considered the perspectives of surface water stakeholders. However, it is also critical to understand the perspectives of groundwater stakeholders. Finally, the study looked into how the irrigation network was used. When assessing the views, future research could address how people adapt to water scarcity or how a socio-hydrological approach influences the success or failure of management policies.

Data availability

Data, associated metadata, and calculation tools are available from Farahnaz Rostami (fr304@yahoo.com).

Author contributions

Fatemeh Javanbakht Sheikhahmad (Writing—original draft, Writing—review & editing), Farahnaz Rostami (Supervision, Writing—review & editing), Hossein Azadi (Supervision, Validation, Writing—review & editing), Hadi Veisi (Writing—review & editing), Farzad Amiri (Writing—review & editing), and Frank Witlox (Writing—review & editing)

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Conflicts of interest

There is no conflict of interest.

Disclaimer

The research protocol was reviewed and approved by the Razi University Research Board and the appropriate ethical approval has been obtained. All participants in the interviews and questionnaires provided written informed consent prior to enrollment in the study and voluntarily shared their insights. Their responses were used anonymously solely for research purposes. At no stage of the research was their photograph, name, or personal information provided. All responses were kept confidential and to ensure anonymity, the data were analyzed and reviewed as a group, not individually.

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