Causal Analysis of Key Factors Enhancing Drought Resilience through Water Management: A Hybrid Content Analysis, Fuzzy Delphi, and DEMATEL Approach

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Abstract

This study aims to identify and analyze the key factors affecting drought resilience through water management and to examine the causal relationships among them. A mixed-methods sequential design was applied. First, a meta-synthesis and content analysis of studies published between 2005 and 2025 identified the main resilience factors. Then, the fuzzy Delphi method validated these factors through expert consensus, and fuzzy DEMATEL was used to analyze causal relationships among them. The results identified five main dimensions and fourteen components influencing drought resilience through water management. The fuzzy DEMATEL results showed that development of interactions and communications had the greatest influence within the system. Soft infrastructure development, cooperation and coordination, local community empowerment, technical water management, and continuous monitoring were the most influential components. The findings are mainly based on expert opinions and the context of Iran, which may limit their generalizability. However, the study provides a useful framework for resilience-oriented water management and policymaking. This study offers an integrated framework combining meta-synthesis, fuzzy Delphi, and fuzzy DEMATEL to provide a causal understanding of the factors affecting drought resilience through water management.

Keywords: Drought resilience, Water management, Content analysis, Fuzzy Delphi, Fuzzy DEMATEL.

1 Introduction

Climate change is undoubtedly the most severe challenge facing mankind and has the potential to affect global water resources, human health, and energy infrastructure (Liu et al. 2018). Climate change increases drought risk, mainly due to temperature and precipitation changes (Tüzel et al. 2025). The increasing number and intensity of extreme weather events caused by climate change, particularly droughts, are an unprecedented challenge to global food security systems (Rane et al. 2025). The number and duration of droughts have increased by 29% globally since 2000, and more than three-quarters of the world's population is projected to be affected by drought by 2050 (Ling et al. 2023). Drought, as one of the most important environmental and economic challenges of this century, has devastating effects on human societies and not only endangers food and water security, but can also lead to widespread migration, increased poverty, and exacerbated social inequalities (Savari et al. 2023).

On the other hand, due to its location in a dry geographical belt and desert strip, Iran is considered one of the regions with the least rainfall on the planet. For this reason, water resources are limited, and drought is common in most areas. Accordingly, Iran is in a state of severe water crisis (Yadegarifar et al. 2023). However, in the face of a devastating phenomenon such as drought, the prevailing approach to reducing the extent of damage and controlling its effects in most parts of the world, including Iran, is still passive (Shen et al. 2022), and so practical solutions are still needed to address this risk (Tüzel et al. 2025). Among the various approaches and solutions proposed to deal with the drought phenomenon, the term resilience has been presented as a key concept in the crisis management literature (Wang et al. 2025). Today, there are significant changes in the ways of dealing with risks; the dominant perspective has shifted from focusing solely on reducing vulnerability to increasing resilience to disasters (Eftekhari et al. 2014). Resilience is defined as the adaptation and flexibility of the local community in the face of changes resulting from disasters, along with the reduction of socio-economic, physical and infrastructural vulnerability (Cheshmehzangi 2020). Resilience is thought of as the ‘ability of a system, community or society exposed to hazards to resist, absorb, accommodate and recover from the effects of a hazard in a timely and efficient manner (Rana 2020). Resilience is a combination of absorbing disturbances and reaching a state of equilibrium, self-reorganization, and increasing the capacity for learning and adaptation (Pietrucha-Urbanik and Rak 2023). Resilience, as a management and development framework, increases the capacity of human and natural systems to prevent, adapt to and rebuild sustainably against climate change. It includes the ability to maintain social cohesion, collective cooperation, build support networks and promote public participation in local decision-making processes (Abad et al. 2025). Increasing resiliency is the most important factor in maintaining the flexibility of socio-environmental systems and combating drought (Vazirian et al. 2021).

Studies conducted in Iran indicate that the prevailing approach to drought management is crisis management. This approach focuses on measures and activities implemented after a drought to help communities recover and rebuild (Yadegarifar et al. 2023). Also, these studies have emphasized the importance of drought risk management over crisis management in planning and policy-making systems. Accordingly, the prevailing approach in Iran can be characterized as retrospective rather than prospective, and reactive rather than proactive (Hatami et al. 2025). Therefore, it is important to consider approaches that proactively manage the effects and consequences of drought, as this topic has received limited attention in previous research. One such approach is to enhance resilience capacities, particularly through effective water resources management, which can contribute to a comprehensive drought management strategy (Bebermeier et al. 2023).

The issue of water resources management is worth considering because, with the excessive and indiscriminate exploitation of surface and groundwater resources, water shortages have become critical (Wang et al. 2025). Given the importance of successive droughts in Iran, attention must be paid to improving resilience under such conditions. Therefore, it is essential to carefully pursue strategies to improve water-use efficiency and manage Iran's water resources effectively (Vazirian et al. 2021), because the lack of proper management of water resources has devastating effects on the productive, economic, social, and environmental sector (Pot 2023). However, regarding the subject of the present research, studies show that there is a clear research gap in the level of previous research in this field.

Therefore, based on the identified research gap in enhancing drought resilience through water management, this study aims to conduct a causal analysis of the factors contributing to increased resilience. In addition, given the need to translate research findings into policy and practical interventions, this study aims to propose a set of strategies for drought resilience. These strategies are designed to be local, realistic, and culturally and socially appropriate, focusing on effective water resources management. They can be applied at various levels of policymaking and intervention in the drought sector, representing an important step toward reducing the damages caused by drought and mitigating its impacts. Accordingly, this study seeks to answer the following three key questions:

1. What are the success factors of drought resilience through water management?

2. How is the success factor assessment for drought resilience through water management?

3. What is the cause-and-effect relationships and the degree of influence and being influenced of each success factor for increasing resilience to drought through water management?

In accordance with the research objective and questions, the present study is organized as follows: Part 1: Introduction, Part 2: Methodology, Part 3: Research Findings in two subsections: Qualitative Findings and Quantitative Findings. Part 4: Discussion and Part 5: Conclusion.

2 Methodology

This research is descriptive-exploratory in nature, and the research method used in this study is based on a mixed research strategy (qualitative-quantitative of sequential type). The qualitative part of the research was based on 2 phases. The first phase involved using the content analysis method in a meta-synthesis approach to identify success factors for enhancing resilience to drought through water management. In the second phase, the fuzzy Delphi method was applied to evaluate these factors from the perspective of experts. In the quantitative phase, the network of cause-and-effect relationships among the dimensions and components identified in the qualitative phase was analyzed. Then, the fuzzy DEMATEL technique was applied to determine the extent to which each component influences others, is influenced by others, and its overall impact.

In the first phase of the present study, research related to the topic published between 2005 and 2025 in reputable databases, including Emerald Insight, ScienceDirect, and Wiley Online Library, was reviewed. In this phase, a non-probability purposive sampling method was employed, and articles were selected through keyword-based searches relevant to the research topic. The sample size was determined based on the principle of theoretical saturation, whereby the review continued until no new qualitative data emerged. In the first phase of the study, a meta-synthesis analysis was conducted following the method of (Sandelowski and

Barroso 2006). This process comprised seven steps: (1) formulation of research questions, (2) systematic review of papers using relevant keywords, (3) selection of appropriate references based on title, abstract, content, and details, (4) extraction of information from the selected references, (5) analysis, synthesis, and integration of findings, (6) quality control, and (7) presentation of results.

In the second phase, the fuzzy Delphi analysis, the participants included 9 experts as members of the Delphi panel and the Delphi process was carried out in 2 rounds until the convergence of opinions. These experts include two groups: academic experts and executive experts. Academic experts have at least an assistant degree and 10 years of work experience, and are familiar with the research topic. Executive experts consist of managers, supervisors, and deputies from various departments involved in water resources management, who also have at least 10 years of work experience and knowledge of the topic under discussion. It is worth noting that the steps of implementing the fuzzy Delphi technique to evaluate dimensions and components in the form of 5 steps are discussed in the research findings section.

The recruitment and data-collection process involving the expert panel was conducted over a two-month period, from 1 January 2025 to 28 February 2025. Before participation, all experts were informed about the purpose of the study, the nature of their participation, and the intended academic use of their responses. Participation was voluntary, and all experts provided verbal informed consent before completing the Delphi questionnaires and providing their expert judgments. No personally identifying information, including names, telephone numbers, email addresses, or other direct identifiers, was collected or retained. Ethical approval was not obtained for this study.

In the third phase, the fuzzy DEMATEL method was employed to analyze the network of causal relationships. Data were collected from nine academic experts, each holding at least an assistant professorship and possessing a minimum of ten years of professional experience, all of whom are well-versed in the research topic. The following outlines the steps undertaken to implement the fuzzy DEMATEL method:

1. Designing fuzzy linguistic expressions

After identifying the criteria, n by n matrix is constructed, where n represents the number of criteria. Experts are then asked to describe the relationships between the criteria using verbal expressions. Finally, after data collection, the responses are converted into fuzzy values in the following form. For fuzzification, Chang's fuzzy triangular number (Chang 1996) is used as shown in Table 1.

TABLE 1 Triangular fuzzy numbers associated with verbal variables.

Verbal variable	Scale	Triangular Fuzzy Number
No impact	0	(0,0,0.25)
Very little impact	1	(0,0.25,0.5)
Little impact	2	(0.25,0.5,0.75)
High impact	3	(0.5,0.75,1)
Very high impact	4	(0.75,1,1)

2. Calculating the direct correlation matrix using the average of experts' opinions

In this step, the opinions of different experts are aggregated using the fuzzy average method. Using the following equation:

$$Z_{ij} = \left[\frac{1}{P}\ (Z^1 \oplus\ Z^2\ \oplus \ldots Z^P)\right]_{n*n}$$

(1)

where, P is the number of experts, Z^1 is the pairwise comparison matrix of the first expert, Z^2 is the pairwise comparison matrix of the second expert, Z^p is the pairwise comparison matrix of the P^{th} expert, and Z is the triangular fuzzy number, $Z_{ij}= a_{ij}, b_{ij}, c_{ij}$.

3. Calculating the normalized average of expert opinion

In this step, the initial direct correlation matrix is normalized using the following relationship:

$$r = \frac{Z_{ij}}{r} = \left(\frac{a_{ij}}{r}\ .\ \frac{b_{ij}}{r}.\ \frac{c_{ij}}{r}\right) = \left(a_{ij}.\, b_{ij}.\, c_{ij}\right)$$

(2)

$$r = max_{1\le i\le n}\left(\sum_{j=1}^{n} c_{ij}\right)$$

(3)

where, a_{ij}, b_{ij}, c_{ij} are the lower, middle and upper bounds of the triangular fuzzy number, respectively, and r is the sum of the upper bounds of each row.

4 and 5. Calculating the fuzzy total relation matrix and defuzzifying

Fuzzy operations produce inherently fuzzy results, which are difficult to interpret directly. Therefore, these results must be converted into crisp values through a process called defuzzification. Various defuzzification methods exist, and in this study, Rubens' method is employed. In this equation, a, b, and c represent the lower, middle, and upper bounds of a triangular fuzzy number, respectively, and the defuzzified value is calculated as follows:

$$B = \frac{(a+2b+c)}{4}$$

(4)

6. Calculating the degree of influence and being influenced and interaction of each factor

In this step, the degree of influence and being influenced and interaction of each factor is calculated using the total non-fuzzy matrix in the previous step, as follows:

D: The sum of the numbers of each row (total non-fuzzy matrix) shows the degree of influence of each factor.

R: The sum of the numbers of each column (total non-fuzzy matrix) shows the degree of being influenced of each factor.

D-R: If this number is positive, the variable is a causal variable, and if it is negative, it is considered a consequence.

D+R: The degree of influence of the factor in the system. The higher this number, the more interaction that factor has with other factors in the system.

7. Drawing a diagram of the intensity of influence and being influenced (causal and effect diagram)

To draw this diagram, the calculation of D-R (vertical axis of the diagram) and D+R (horizontal axis of the diagram) is taken into account, and the position of each factor is determined in the diagram according to these two numbers.

8. Drawing the graph of network relationships

At this step, in order to draw the network relationships, it is necessary to calculate the threshold value. With this method, minor relationships are ignored, and a network of significant relationships is drawn. The formula for calculating the threshold is as follows:

$$a = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} tij}{N}$$

(5)

3 Results

The results of the present study are presented in 3 phases:

3.1 Results of phase 1

This part of the study aims to answer the question, "What are the success factors of drought resilience through water management?" In this regard, the seven-step model of Sandelowski and Barroso (2006) was used, and papers published in the period, from 2005 to 2025, were considered.

Steps 1 and 2: Systematic literature review and study selection

In these two steps, a systematic review of research related to success factors for increasing drought resilience through water management in the last 20 years from 2005 to 2025 was conducted based on keywords related to this topic.

Step 3: Search and selection of texts

In this step, the extracted papers were filtered based on a targeted search. After identifying 78 initial relevant studies, the review process included: reviewing the title, abstract, content of the studies and research method. Finally, after four steps of filtering, 42 of the 78 studies were rejected, and 36 studies were selected. A schematic view of the process of reviewing and selecting references for the present study is shown in Figure 1.

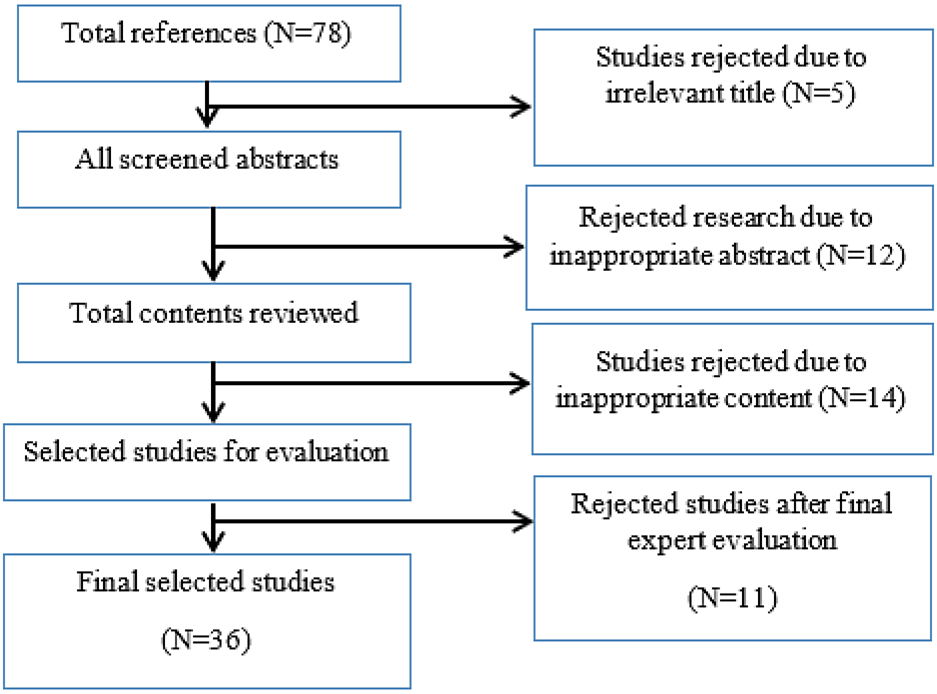

FIGURE 1 Process of reviewing and selecting references.

Step 4: Information extraction

This step is dedicated to the codes extracted from the selected papers. A sample of the extracted codes is provided in Table 2.

TABLE 2 Sample of codes extracted from selected papers. related to identifying success factors in increasing drought resilience through water management.

Selected codes from the paper	Ref.	Selected codes from the paper	Ref.
Attention to local communities	Murgatroyd et) (al. 2022	Investing in water infrastructure	Savari et al.) (2023
Awareness raising		Developing water management strategies	
Analysis of water supply system resilience		Increasing storage in surface reservoirs	
Allocation of budget and financial resources		Educating local communities	
Managers' understanding of drought risk	(Pot 2023)	Increasing productivity	(Li et al. 2022)
Policymaking		Cultivation pattern reform	
Investment in water infrastructure		Government support	
Formation and activities of NGOs (non-governmental organizations)		Comprehensive and continuous evaluation	

New irrigation methods		Participation of all stakeholders	
Government assistance	(Maltou and Bahta 2019)	Raising awareness among the community	(Bebermeier et al. 2023)
Promoting the resilience of local communities		Strengthening infrastructure	
Increasing access to financial resources		Increasing resilience	
Providing educational and extension services		Communication and interaction of all stakeholders	
		Developing indigenous knowledge	
		Using validated methods to predict potential risks	

Step 5: Analysis of qualitative findings

In this step, based on the codes extracted from 36 articles, these codes were linked to create and present subcategories (components) and then main categories (dimensions) related to the research topic. Table 3 summarizes the output of this step.

TABLE 3 Linking of relevant codes and construction of sub-categories and main categories regarding identifying success factors in increasing drought resilience through water management.

Basic codes	Subcategories (Components)	Symbol	Main categories (Dimensions)	Symbol
Government support	Supportiveness	A1	Governance requirements	A
Providing technical, insurance and financial support services				
Support and effectiveness of the institutional system				
Access to emergency services				
Formulating water management strategies	Policy and Strategy Development	A2		
Proper and appropriate planning				
Policymaking				
Investing in water infrastructure	Paying Attention to Hard Infrastructure Development	A3		
Strengthening infrastructure				

Repairing and protecting critical networks and infrastructure				
Formation and activities of NGOs	Paying Attention to Soft Infrastructure Development	A4		
Expanding communication channels				
Collaboration	Cooperation and Coordination	B1	Developing interactions and communications	B
Exchange of best practices				
Communication and engagement of all stakeholders				
Reducing government authority and moving towards a participatory model	Partnership	B2		
Involving local communities				
Awareness raising	Empowering Local Communities	C1	Socio-cultural requirements	C
Education and promotion				
Attention to indigenous knowledge and its utilization				
Diversification of farmers' livelihoods	Diversifying Livelihoods and Household Economy	C2		
Diversifying the skills and employment of agricultural operators				
Adaptation measures for farmers				
Cropping pattern modification	Changing and modifying traditional cropping patterns	D1	Technical requirements	D
Cropping pattern change				
Cultivation of drought-resistant plants				
Climate-adapted water management				
Climate-adapted soil management	Developing and implementing new systems and methods	D2		
Establishment of a drought monitoring and early warning system				

Climate-adapted information management				
Using reliable methods to predict potential risks				
Analysis of water supply system resilience				
Development of new technologies				
Addressing climate change requirements	Technical issues in the field of water resources management	D3		
Increasing storage in surface reservoirs				
Optimized water utilization and harvesting				
Increasing productivity				
Establishing control systems	Continuous measurement and assessment	E1	Development of supervisory measures	E1
Evaluating the level of groundwater exploitation				
Smartization of water consumption metrics				
Eliminating the intervention of non-specialized sectors	Preventing excessive exploitation	E2		
Implementing deterrent laws				
Continuous review of the performance of responsible institutions	Continuous evaluation of the performance of responsible organizations	E3		

Step 6: Quality control

In this study, the Kappa index was used to assess the quality of the studies regarding the extracted codes. To calculate this coefficient, the opinions of two expert coders regarding the 14 proposed components in Table 3 were used and the results showed that the agreed Kappa was 0.89 and, in this respect, the components were approved.

Step 7: Presentation of the report and research findings

According to the steps of the meta-analysis, it was determined that the success factors for increasing resilience to drought through water management consist of 5 dimensions and 14 components (as shown in Table 3).

3.2 Results of phase 2

This part of the research is in line with answering the second research question, " How is the success factor assessment for drought resilience through water management?" As mentioned earlier, to evaluate effective factors and components, the fuzzy Delphi method was used relying on the opinions of experts (9 experts as members of the Delphi panel). The steps for implementing the fuzzy Delphi technique to evaluate dimensions and components are as follows:

1. Identifying the appropriate range for fuzziness of verbal expressions

In this step, after sending Delphi questionnaires (based on the components listed in Table 3) to the experts, they expressed their level of agreement through the five verbal variables as described in Table 1. Table 1 shows how to convert linguistic variables into fuzzy numbers and the scales related to it.

2. Fuzzy aggregation of fuzzy numbers

In this step, first the opinion of each expert regarding each criterion was identified and then the fuzzy geometric mean method was used to aggregate the opinions of 9 experts for fuzzy aggregation.

3. Defuzzification of numbers

After the fuzzy mean of the experts' opinions was calculated, the resulting number should be defuzzified (taking into account the specified in Table 1). After defuzzification, the resulting number will be between 0 and 1. Several methods have been proposed for defuzzification. In this study, the simple average method was used, where the upper bound, lower bound, and middle value of each fuzzy number are summed and divided by three.

4. Selecting the threshold intensity and screening criteria

At this step, the threshold intensity was set at 0.7 (Hsu et al. 2010). Accordingly, indicators below this threshold were eliminated, and the Delphi process continued to the next round. It is worth mentioning that the Delphi rounds continue until no more indicators are eliminated or added.

TABLE 4 Aggregation fuzzified criteria numbers and defuzzification (definite score) and screening based on comparison with threshold severity in the first Delphi round.

Criteria	Fuzzy score			Definite Score	Comparison results with threshold intensity
	L	M	U		
Supportiveness	0.63	0.88	0.97	0.82	Component acceptance
Policy and Strategy Development	0.50	0.75	0.93	0.72	Component acceptance
Paying Attention to Hard Infrastructure Development	0.58	0.83	0.97	0.79	Component acceptance
Paying Attention to Soft Infrastructure Development	0.48	0.73	0.91	0.71	Component acceptance
Cooperation and Coordination	0.58	0.82	0.92	0.77	Component acceptance
Partnership	0.50	0.75	0.93	0.80	Component acceptance
Empowering Local Communities	0.57	0.82	0.97	0.78	Component acceptance
Diversifying Livelihoods and Household Economy	0.64	0.89	0.98	0.84	Component acceptance
Changing and modifying traditional cropping patterns	0.67	0.92	0.98	0.86	Component acceptance
Developing and implementing new systems and methods	0.61	0.86	0.98	0.82	Component acceptance
Technical issues in the field of water resources management	0.58	0.82	0.92	0.77	Component acceptance
Continuous measurement and assessment	0.54	0.79	0.94	0.76	Component acceptance
Preventing excessive exploitation	0.67	0.92	0.98	0.86	Component acceptance
Continuous evaluation of the performance of responsible organizations	0.48	0.73	0.91	0.71	Component acceptance

Examining the results of the first Delphi round (Table 4) indicates that all criteria achieved a fuzzy mean score above the predefined threshold. Therefore, no component was eliminated at this stage. Based on these results, a second Delphi round was conducted using a questionnaire that included all criteria identified in the first round (Table 5). The outcomes of the two Delphi rounds were subsequently compared in Step 5 (Table 6) in order to reach consensus.

TABLE 5 Aggregation fuzzified criteria numbers and defuzzification (definite score) and screening based on comparison with threshold severity in the second Delphi round.

Criteria	Fuzzy score			Definite Score	Comparison results with threshold intensity
	L	M	U		
Supportiveness	0.64	0.89	0.98	0.84	Component acceptance
Policy and Strategy Development	0.57	0.82	0.95	0.78	Component acceptance
Paying Attention to Hard Infrastructure Development	0.61	0.86	0.98	0.82	Component acceptance
Paying Attention to Soft Infrastructure Development	0.48	0.73	0.91	0.71	Component acceptance
Cooperation and Coordination	0.55	0.80	0.94	0.77	Component acceptance

Partnership	0.50	0.75	0.92	0.72	Component acceptance
Empowering Local Communities	0.54	0.79	0.94	0.76	Component acceptance
Diversifying Livelihoods and Household Economy	0.58	0.83	0.97	0.79	Component acceptance
Changing and modifying traditional cropping patterns	0.57	0.82	0.95	0.78	Component acceptance
Developing and implementing new systems and methods	0.64	0.89	0.98	0.84	Component acceptance
Technical issues in the field of water resources management	0.60	0.85	0.98	0.81	Component acceptance
Continuous measurement and assessment	0.58	0.82	0.92	0.77	Component acceptance
Preventing excessive exploitation	0.61	0.86	0.98	0.82	Component acceptance
Continuous evaluation of the performance of responsible organizations	0.50	0.75	0.92	0.72	Component acceptance

5. Reaching consensus

At this step, if the fuzzy distance of the numbers in two consecutive rounds is less than 0.1 (Hsu et al. 2010), the survey process is stopped. The Table 6 shows the difference in the results of the first and second Delphi rounds.

TABLE 6 Difference between the results of the first and second rounds.

Criteria	First round result	Second round result	Difference	Result
Supportiveness	0.82	0.84	0.02	acceptance
Policy and strategy development	0.72	0.78	0.06	acceptance
Paying attention to hard infrastructure development	0.79	0.82	0.03	acceptance
Paying attention to soft infrastructure development	0.71	0.71	0	acceptance
Cooperation and coordination	0.77	0.77	0	acceptance
Partnership	0.80	0.72	0.08	acceptance
Empowering local communities	0.78	0.76	0.02	acceptance
Diversifying livelihoods and household economy	0.84	0.79	0.05	acceptance
Changing and modifying traditional cropping patterns	0.86	0.78	0.08	acceptance
Developing and implementing new systems and methods	0.82	0.84	0.02	acceptance
Technical issues in the field of water resources management	0.77	0.81	0.04	acceptance
Continuous measurement and assessment	0.76	0.77	0.01	acceptance
Preventing excessive exploitation	0.86	0.82	0.04	acceptance
Continuous evaluation of the performance of responsible organizations	0.71	0.72	0.01	acceptance

The results presented in Table 6 show that the difference between the defuzzified averages of experts' opinions for each criterion across the two Delphi rounds is less than 0.1. Therefore, the survey was terminated at this stage, indicating that consensus was achieved among the experts for all criteria.

3.3 Results of phase 3

This part of the research is aimed at answering the third research question, which is " What are the cause-and-effect relationships and the degree of influence and being influenced of each success factor for increasing resilience to drought through water management?" As mentioned earlier, to answer this question, the fuzzy DEMATEL method was used based on the following steps and relying on the opinions of 9 academic experts. At the beginning of the study, the fuzzy average of the experts' opinions on the dimensions (the main criteria listed in Table 3) was calculated using Equation (1) and is presented in Table 7.

TABLE 7 Average expert opinions.

	A			B			C			D			E		
A	0.000	0.000	0.000	0.333	0.555	0.777	0.500	0.722	0.888	0.416	0.638	0.805	0.222	0.388	0.638
B	0.361	0.611	0.805	0.000	0.000	0.000	0.333	0.555	0.777	0.361	0.583	0.722	0.305	0.527	0.7500
C	0.3611	0.5833	0.8056	0.5000	0.7500	0.9167	0.000	0.000	0.000	0.2500	0.472	06667	0.055	0.2500	0.5000
D	0.4167	0.6111	0.8056	0.5000	0.7500	0.9167	0.3333	0.52	0.750	0.000	0.000	0.000	0.166	0.361	0.611
E	0.3889	0.6389	0.8611	0.4722	0.7222	0.944	0.444	0.66	0.833	0.250	0.500	0.694	0.000	0.000	0.000

In Table 8, the normalized average of experts' opinions on the main criteria (or dimensions) is calculated using Equations (2) and (3) and is subsequently reported.

TABLE 8 Normalized average of expert opinions.

	A			B			C			D			E		
A	0.000	0.000	0.000	0.092	0.153	0.215	0.142	0.20	0.249	0.111	0.171	0.219	0.058	0.111	0.181
B	0.100	0.170	0.224	0.000	0.000	0.000	0.093	0.156	0.218	0.097	0.157	0.197	0.081	0.141	0.204

C	0.097	0.157	0.219	0.139	0.209	0.255	0.000	0.000	0.000	0.065	0.126	0.182	0.014	0.066	0.136
D	0.113	0.166	0.221	0.142	0.211	0.256	0.095	0.150	0.212	0.000	0.000	0.000	0.044	0.097	0.167
E	0.107	0.177	0.239	0.128	0.198	0.260	0.124	0.186	0.234	0.066	0.136	0.192	0.000	0.000	0.000

Table 9 presents the total fuzzy relationship matrix of the main criteria, along with the defuzzified values calculated using Equation (4).

TABLE 9 Calculation of the fuzzy relationship matrix.

	A			B			C			D			E		
A	1.060	1.243	2.094	0.156	0.408	1.352	0.190	0.422	1.305	0.151	0.367	1.162	0.084	0.261	1.030
B	0.148	0.386	1.261	1.066	1.270	2.156	0.146	0.384	1.267	0.136	0.353	1.132	0.103	0.283	1.033
C	0.136	0.352	1.198	0.179	0.417	1.2970	1.0515	1.2234	2.029	0.104	0.309	1.069	0.042	0.210	0.939
D	0.161	0.383	1.269	0.194	0.445	1.372	0.150	0.378	1.274	1.051	1.218	1.977	0.073	0.250	1.017
E	0.160	0.415	1.355	0.189	0.463	1.453	0.180	0.431	1.363	0.117	0.359	1.204	1.032	1.176	1.931

	A	B	C	D	E
A	0.3867	0.5504	0.5564	0.4926	0.3899
B	0.5210	0.4168	0.5202	0.4768	0.4082
C	0.4874	0.5503	0.3598	0.4325	0.3336
D	0.5219	0.5821	0.5182	0.3467	0.3791
E	0.5554	0.6038	0.5693	0.4902	0.3056

In Table 10, degree of influence and being influenced and interaction of each factor has been calculated and presented using the total non-fuzzy matrix in the previous step.

TABLE 10 Prioritization and internal relationships of the research dimensions.

Criteria	R Degree of being influenced	D Degree of influence	D-R relation	D+R prominence
A	2.4471	2.360663	-0.0864	4.8077
B	2.6627	2.335859	-0.3268	4.9986
C	2.4912	2.169074	-0.3221	4.6603
D	2.2311	2.331561	0.1004	4.5627
E	1.8580	2.481818	0.6239	4.3398

Based on the D-R and D+R values presented in Table 10, a cause-and-effect diagram illustrating the main criteria of the research model is constructed, as shown in Figure 2. This diagram indicates the degree of influence and being influenced between the criteria as well as their importance. The outcomes indicate that criterion B, which relates to the development of interactions and communications, has a higher D+R value. Therefore, its influence within the system is greater than that of the other criteria. However, due to the lower D-R value of criterion B, which relates to development of interactions and communications, the level of being influenced of this factor in the system is greater than that of the other criteria.

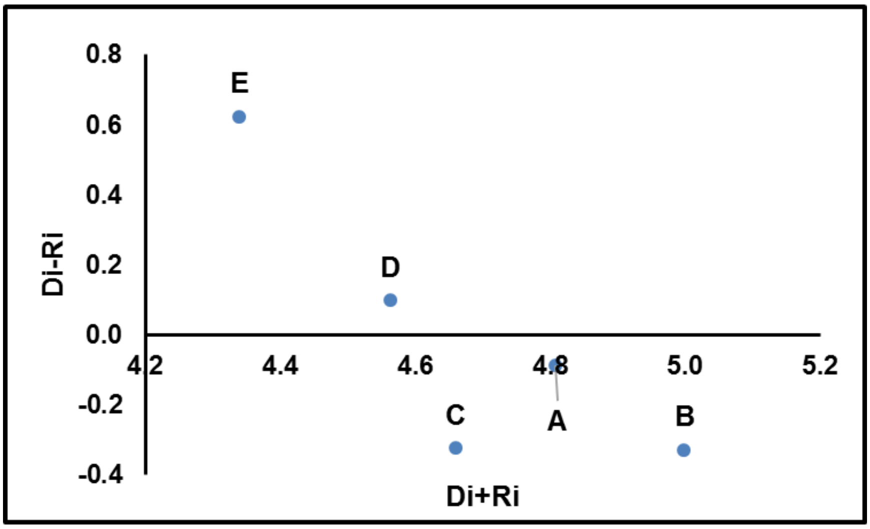

FIGURE 2 Cause and effect diagram of the main criteria of the research model.

The threshold value for the main criterion, used to draw the network graph, was calculated using Equation (5) and determined to be 0.578. Based on this value, the type of interaction for each criterion is presented in Table 11. Using the information from this table, the network relationship map of the main criteria in the research model (Figure 3) was created. In this map, 0 indicates the absence of a relationship (no arrow), while 1 indicates the presence of a relationship (arrow present).

TABLE 11 Interaction of the main criteria of the comparative research model with the threshold value.

	A	B	C	D	E
A	0	1	1	1	0
B	1	0	1	1	0
C	1	1	0	0	0
D	1	1	1	0	0
E	1	1	1	1	0

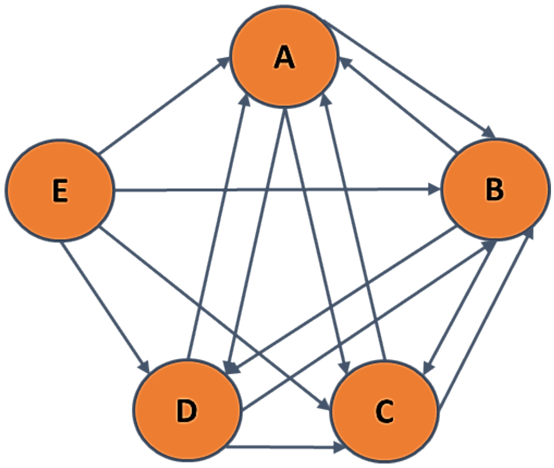

FIGURE 3 Map of network relationships of the main criteria of the research model.

3.4 Implementing fuzzy DEMATEL for research model sub-criteria

It is worth mentioning that the steps used to implement Fuzzy DEMATEL for the research model's sub-criteria are the same as those applied to the main criteria. To keep the presentation concise, only the prioritization table and the internal relationships of the sub-criteria are provided (Table 12). These are organized according to the components corresponding to the five dimensions.

TABLE 12 Prioritization and internal relationships of the sub-criteria of the research model separately.

Sub-criteria	R	D	D-R	D+R
A1	1.8949	2.64334	0.7484	4.5383
A2	2.5488	2.020028	-0.5288	4.5688
A3	2.3508	2.462144	0.1114	4.8129
A4	2.6357	2.338063	-0.2977	4.9738
B1	5.2500	5.169168	-0.0808	10.4191
B2	5.1692	5.249974	0.0808	10.4191
C1	1.4531	1.761851	0.3088	3.2149
C2	1.7619	1.453091	-0.3088	3.2149
D1	1.4172	1.683606	0.2664	3.1008
D2	1.7513	1.187137	-0.5642	2.9385
D3	1.5294	1.803506	0.2742	3.3329
E1	2.2026	1.893447	-0.3091	4.0960
E2	1.7181	2.117978	0.3998	3.8361
E3	1.9513	1.851997	-0.0993	3.8033

Regarding the sub-criteria of the governance requirements dimension, criterion A4 shows a higher D+R value. This indicates that greater attention to the development of soft infrastructure is required. Consequently, the influence of this factor on the system is higher than that of the other criteria. However, since criterion A2 (policymaking and strategy formulation) has a lower D-R value, its influence within the system is higher than that of the other criteria. Also, the threshold value calculated for this sub-criterion is 0.5919. Regarding the sub-criteria of the development of interactions and communications dimension, the values of D+R and D-R for both sub-criteria are the same, and therefore, the degree of influence and being influenced is the same. Also, the calculated threshold value is 2.6190.

Regarding the sub-criteria of the socio-cultural requirements dimension, the values of D+R and D-R for both sub-criteria are the same. Therefore, the degree of influence and being influenced is the same. Also, the calculated threshold value is 0.8131. Concerning the sub-criteria of the technical requirements dimension, given the higher D+R value associated with criterion D3, technical issues in the field of water resources management, the degree of influence of this factor in the system is higher than that of the other criteria. However, given the lower D-R value associated with criterion D2, the development and application of new systems and methods, the degree of being influenced of this factor in the system is higher than that of the other criteria. Also, the calculated threshold value is 0.5224. Among the sub-criteria of the development of supervisory measures dimension, criterion E1, which pertains to continuous measurement and assessment, exhibits the highest D+R value. This suggests that it has a stronger influence on the system than the other criteria. However, given the lower D-R value associated with criterion E1, the degree of being influenced of this factor in the system is higher than that of the other criteria. Also, the calculated threshold value is: 0.6564.

4 Discussion

This research was conducted with the aim of causal analysis of success factors in increasing resilience to drought through water management. The present research was conducted in 3 phases. In the first phase, content analysis based on the use of the meta-synthesis method and systematic review of relevant studies published between 2005 and 2025 was conducted to identify success factors in increasing drought resilience through water management. As shown in Table 3, the systematic review of 36 selected studies resulted in the identification of five main dimensions and fourteen components associated with success factors for drought resilience. The identified dimensions comprise governance requirements, interaction and communication development, socio-cultural requirements, technical requirements, and supervisory measure development. The second phase was dedicated to evaluating the success factors in increasing resilience to drought through water management from the experts' perspective using the Delphi method. The results presented in Table 6 show that expert consensus was achieved for all criteria. Accordingly, all components were approved, since the difference in defuzzified mean values between the two Delphi rounds was below the threshold of 0.1.

Finally, in the third phase, after identifying and evaluating the success factors for increasing resilience to drought through water management, causal relationships between these factors and system components were established using the DEMATEL technique. The results showed that the criterion of development of interactions and communications in the system has a higher degree of both influence and being influenced compared to the other criteria. Effective communication and the exchange of experiences among national experts, together with cooperation with local and other stakeholders, can help create and develop an up-to-date knowledge network on water management. This network can improve strategies for addressing drought-related issues and, in turn, enhance resilience to drought. Such a knowledge network has the potential to play a key role in empowering smallholder farmers and resolving disputes over water issues among stakeholders. On the other hand, examining the degree of being influenced of the components by separating them into 5 factors indicated that:

In the governance requirements dimension, the sub-criteria particularly emphasize the development of soft infrastructure. Meanwhile, within the development of the interactions and communications dimension, the components of cooperation, coordination, and partnership building exert a stronger influence than the other components. Emphasizing the development of soft infrastructure, as well as fostering cooperation and coordination, is crucial. Without proper governance in soft infrastructure development (even despite the development of hard infrastructure), sustainable resilience to drought cannot be achieved. This is because the development of soft infrastructure emphasizes the expansion of communication channels to further utilize the capacity of all stakeholders and non-governmental organizations effective in the field of drought and water resources management. The existence of these communication channels can help improve institutional coordination, reduce potential conflicts between the government and other stakeholders and improve integrated decision-making, which in turn will enhance resilience. In such circumstances, it can be expected that by improving the level of coordination and transparency of relations between the parties, circumvention of laws, informal water transfers, and over-abstraction by local communities will be less common, and conditions will be created for improving resilience.

In the case of the sub-criteria of the socio-cultural requirements dimension, the components of empowering local communities and diversifying livelihoods and household economies both have the same impact. In explaining this, it can be said that drought resilience through water management is not just a technical issue, but the role of social and cultural issues of the communities involved is important here. Because the local community is no longer a regular consumer of water, but can be considered a major actor. By empowering local communities and diversifying their economies, it is possible to reduce their direct dependence on the critical issue of water and reduce the economic risk of drought. In other words, by relying on the empowerment of local communities, the acceptance of water policies in these communities is improved, cooperation is strengthened, and social conflicts caused by water scarcity are resolved by increasing the level of trust between the government and local communities. In short, this finding indicates that effective drought management through a resilience approach with an emphasis on the role of water management requires the integration of water policies with strategies for empowerment and diversification of local economic livelihoods.

Regarding the sub-criteria of the technical requirements dimension, the technical issues component in the field of water resources management has a greater impact than other components. Paying attention to technical issues in water resources management is crucial for enhancing resilience during droughts. Without proper infrastructure and technology, effective monitoring and control become impossible. Consequently, water distribution may be disrupted, and empirical, non-scientific decisions may replace data-driven, scientific ones. Technical challenges in water resources management can be addressed through preventive planning and hydrological monitoring. These measures help increase storage in surface reservoirs and optimize water use and withdrawal. As a result, they reduce pressure on water resources, improve operational efficiency and flexibility, and decrease the system's vulnerability to drought.

Concerning the sub-criteria of the development dimension of supervisory measures, the continuous measurement and evaluation component has a greater impact than the other components. The importance of the continuous measurement and evaluation component is that whatever is not measured cannot be managed or improved. Continuous measurement and evaluation provide the possibility of modifying policies before deep crises occur and prevent reactive and ad hoc decision-making. Continuous monitoring, by combining quantitative and qualitative data, can help optimize the allocation of water resources and improve and modify the status of the cropping pattern. Therefore, it can be stated that continuous measurement and evaluation promotes drought resilience from a static process to a dynamic, learning and adaptive process and plays a key role in improving resilience.

5 Conclusion

The findings of this study indicate that drought resilience through water management is not a one-dimensional or purely technical issue. Instead, it results from the interaction of five complementary dimensions, including governance, technical factors, socio-cultural requirements, the development of supervisory measures, and the enhancement of interactions and communications. The proposed model suggests that weakness or neglect in any of these dimensions can cause problems for the entire resilience system, even if other dimensions are relatively strengthened. Governance requirements, as a key dimension, regulate and guide other dimensions. By establishing institutional coordination, ensuring transparency in decision-making, and promoting accountability, they provide the foundation for the effective implementation of both technical and social measures. On the other hand, socio-cultural dimensions, as soft substrates, play a decisive role in the acceptance of policies, changing water consumption patterns and the sustainability of technical interventions. It is therefore recommended that drought resilience monitoring and evaluation be conducted in an integrated, multi-level approach. This would allow governance, technical, and social indicators to be monitored simultaneously and continuously, with the results fed directly into the policy-making and implementation processes. It is also necessary to foster both horizontal and vertical interactions among government institutions, the private sector, local communities, and non-governmental organizations. Such interactions enhance the effectiveness of measures by leveraging the synergy of technical knowledge, social capital, and local capacities. Strengthening participatory mechanisms, data exchange and institutional learning can take the presented model beyond the theoretical level and turn it into an operational tool for sustainable drought management at different scales. Overall, the findings of this study can provide practical guidance for policymakers and water managers in prioritizing interventions to increase drought resilience through water management. Finally, it should be noted that, as with most studies, caution is needed when applying the findings of this research. The results may not be generalizable to other places due to the influence of historical experiences, current conditions in Iran, and the perspectives of research experts.

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Authors' Contributions

Zeinab Afzali: Conceptualization, Methodology, Software, Data curation, Formal analysis, Investigation, Validation, Visualization, Writing-original draft.

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Somayeh Amirteimouri: Supervision, Project administration, Resources, Writing-review & editing.

Hossein Mehrabi Basharabadi: Writing, review & editing

Hamidreza Mirzaei khalilabadi: Writing, review & editing

Competing Interests

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

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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