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Drinking water supply for communities affected by natural disaster emergencies: a qualitative study

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Abstract

Background Ensuring access to safe drinking water is vital for reducing health risks and strengthening disaster resilience. In water-scarce Iran, where natural disasters further strain resources, water supply experts play a key role in crisis management. Their firsthand experience across diverse regions provides valuable insights. Despite extensive research on emergency water management, this qualitative study explores key dimensions for optimizing drinking water provision to disaster-affected areas and centers by leveraging their expertise in real disaster scenarios.

Methods This study used a qualitative design with conventional content analysis. Data were collected through purposive sampling with maximum variation until saturation was reached, involving participants with academic and practical experience in water supply management during natural disasters. Data were collected through semi-structured interviews from March to September 2024 and analyzed using Graneheim and Lundman approach. The transcripts were processed using MAXQDA software (version 2020). To ensure the credibility and trustworthiness of the findings, the study followed Lincoln and Guba's criteria, including credibility, transferability, dependability, and confirmability.

Results After analyzing the interviews, 509 initial codes were extracted and grouped into 84 subcategories, 24 categories, and four main themes. These four themes include: prevention and reduction of water supply challenges, covering risk assessment, and legal requirements and standards; preparedness for an optimal response, involving planning, coordination and organization, and training and empowerment; reactive measures namely readiness and initial assessment, and emergency training for the public; and optimal recovery, which focuses on reconstruction, and knowledge management.

Conclusions This study identifies critical factors for enhancing emergency water supply during natural disasters. The proposed innovative measures in this study include equipping emergency water extraction taps on main pipelines, considering the social characteristics of geographic areas in emergency water supply planning, and the crucial role of community participation in water management before and after disasters. These findings can help policymakers and water resource managers develop effective regulations and training programs to enhance disaster preparedness and response.

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Keywords Drinking water, Emergency response, Public health, Crisis, Natural disasters, Qualitative study

Introduction

Natural disaster events typically impact drinking water resources, leading to health issues by limiting access to safe water for affected populations [1, 2]. Recent studies have highlighted that the frequency and intensity of natural disasters, especially those related to climate change, have significantly amplified the pressure on water resources, making access to safe drinking water more difficult, particularly in vulnerable regions [3, 4]. Every year, over 500,000 people worldwide struggle with water scarcity, and more than half of the global population faces drinking water shortages for more than 30 days annually [5, 6]. According to the Global Assessment Report by the United Nations Office for Disaster Risk Reduction (UNDRR(, drought events worldwide adversely affect people's access to water, with over 94% of water pans drying up [7]. Furthermore, a recent study by the UNDRR (2023) asserts that the occurrence of droughts and floods is expected to double by 2050, further straining water access, particularly in developing countries [8]. Statistics show that natural disasters affect more than 270 million people annually, with many suffering from waterborne diseases due to the consumption of contaminated water [9, 10]. For instance, in addition to thousands displaced, around 2,800 people in Haiti died in 2004 due to the lack of clean water following a tropical storm [11].

A study examined the impacts of flooding on the water supply system in Florence, revealing that the system's vulnerability to floods could lead to a threefold increase in the number of affected people [12]. A study on the Dehgolan Plain in Iran used the Water Evaluation and Planning (WEAP) model and Multi-Criteria Decision-Making (MCDM) framework to evaluate groundwater management strategies, highlighting improved irrigation patterns as the most effective approach to increase aquifer volume and reduce groundwater dependence [13]. Similarly, expert knowledge from various sources was gathered in other research to develop optimal decision-making strategies for water supply managers in emergencies, resulting in a model based on the Analytic Hierarchy Process (AHP) method [14]. In another study, the Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE V) technique was employed to evaluate the constraints faced by crisis management organizations and the key factors influencing water supply. This approach helped identify the most effective strategies for addressing challenges in urban water supply systems after natural disasters [15].

A study aimed at assessing the impact of earthquakes on the water distribution system in a coastal city in Lebanon considered the type of pipes used and the area's soil characteristics, ultimately recommending the use of more resilient pipes to withstand seismic stresses [16]. However, the importance of having an Emergency Response Plan (ERP) to handle water-related crises emphasized by a research, proposing a general structure for developing an ERP for Community Water Systems (CWS) [17].

In a study, a system for identifying potable water sources in disaster-affected regions was proposed, enabling victims of natural disasters to easily locate the nearest safe water source during emergencies [18]. key factors in selecting suitable water resources for emergency situations in cities were examined, with a recommendation that each region identify alternative water resources based on established criteria [19]. A model for optimal planning of the recovery process for water distribution systems damaged by earthquakes has been proposed, emphasizing the importance of quickly restoring access to safe water in critical locations such as hospitals [20].

A study examined Australia's water supply system by reviewing ten case studies of management measures implemented during extreme weather events, identifying and categorizing lessons learned for water supply managers across different disaster phases [21]. As highlighted in the Global Assessment Report by the UNDRR, one of the key actions required following the 2017 Mexico earthquake was the implementation of rapid solutions to ensure access to drinking water in informal communities [7, 22]. The lack of safe drinking water in the aftermath of natural disasters causes significant damage across social, economic, and health sectors, often leading to public anger and resentment. Consequently, providing drinking water to affected populations becomes one of the primary priorities in disaster response and relief efforts [9]. As natural disasters continue to increase in frequency and intensity, ensuring access to drinking water in affected areas becomes a major challenge. Urban spaces should be designed with consideration for social and human impacts in disaster management [23]. Previous studies emphasize the need for effective management strategies to mitigate water shortages and prevent waterborne diseases, especially in disaster-prone regions such as Iran [14].

Iran, due to its unique geographical position, is highly susceptible to natural disasters such as floods, earthquakes, and droughts [24]. These disasters not only directly affect the water supply systems of the impacted areas but also exacerbate the overall effects of the disaster [5, 12, 16, 25]. Iran's vulnerability to natural disasters is further compounded by its limited water resources, with several studies showing that more than 70% of the country's population lives in drought-prone areas, making it one of the most water-stressed countries in the region [26, 27]. Despite extensive research on emergency water management, the experiences of Iran's water supply authorities remain underexplored. These authorities have been directly involved in real natural disaster scenarios across various geographical regions in the country, facing challenges firsthand and implementing solutions. Leveraging the experiences of these individuals is crucial, as their expertise provides invaluable insights into optimizing drinking water provision to vital centers in disaster contexts. Therefore, this study aims to bridge this gap by surveying the expert opinions to identify critical factors for optimizing the provision of safe drinking water to affected by natural disasters, including population centers, healthcare facilities, and other vital centers essential for managing emergency conditions in Iran. Additionally, This study addresses key challenges such as inadequate coordination in crisis management and the lack of practical frameworks for emergency water distribution. By identifying critical success factors and proposing context-based solutions, it contributes to bridging the gap between theory and practice in disaster-related water supply management.

Methods

Study design

This study used a qualitative approach, specifically Qualitative Content Analysis (QCA), to examine data systematically and contextually. QCA is a strong interpretive method for analyzing textual qualitative data, aimed at creating new insights, practical frameworks, and guidelines [28]. The objective of this approach is to classify and provide a comprehensive description of a phenomenon.

Sampling

Participants were selected using a combination of purposive and snowball sampling techniques. Purposive sampling allowed us to intentionally recruit individuals with specific expertise relevant to our study. Snowball sampling further facilitated the identification of additional participants through referrals from initial subjects, a method particularly effective for accessing hard-to-reach populations and ensuring a comprehensive understanding of the research topic [29–32]. Integrating purposive and snowball sampling methods enhances research by combining the deliberate selection of key informants with the expansive reach to include hard-to-access individuals, thereby enriching the depth and breadth of data collected.

Ethical clearance was obtained from Iran University of Medical Sciences, followed by securing informed consent from each participant. Participants included managers and experts in water supply, disaster response, university faculty, and volunteers involved in disaster scenarios nationwide. Interviews were conducted from March 2024 to September 2024 until data saturation was achieved.

In our study, the sample size was determined based on the principle of data saturation, a common practice in qualitative research [33]. Data saturation is reached when no new themes or insights emerge from further data collection, ensuring the depth and richness of the information gathered [33]. Previous studies suggest that for in-depth interviews, a sample size ranging from 12 to 30 participants is typically sufficient to achieve saturation, depending on the study's scope and complexity [34, 35]. It has been observed that thematic saturation often takes place within the first twelve interviews, with core themes emerging as early as six interviews [33].

Inclusion and exclusion criteria

Eligible participants included university researchers with expertise in water supply for natural disaster scenarios, (including all types of natural disasters such as earthquakes, floods, droughts, etc.), professionals from water and sewage organizations, the Hilal Ahmar, and municipal representatives with practical experience in disaster-related water supply who expressed a willingness to participate are entered study. These individuals are chosen due to their direct involvement and practical expertise in water supply management. Individuals who lacked direct experience in disaster-related water supply management or did not provide informed consent were excluded from the study.

Data collection

Data were collected from various cities and geographic regions across Iran, a country located in the Middle East, which is prone to a wide range of natural disasters, including earthquakes, floods, and droughts [36]. The selection of diverse regions aimed to ensure a comprehensive understanding of the issues related to water management during natural disasters (Fig. 1). Interviews were performed through semi-structured interviews (Table 1). Each interview began with the question, "1. Based on your scientific and practical experiences in the field of providing safe water during natural disasters, what are the main strengths and weaknesses in our approach?" Follow-up questions, like "Can you elaborate?" or "Did I understand you correctly?" were used based on responses. Interviews were conducted at locations preferred by participants, with some conducted remotely via phone or online due to logistical limitations. With consent, interviews were audio-recorded, averaging 40 min each.

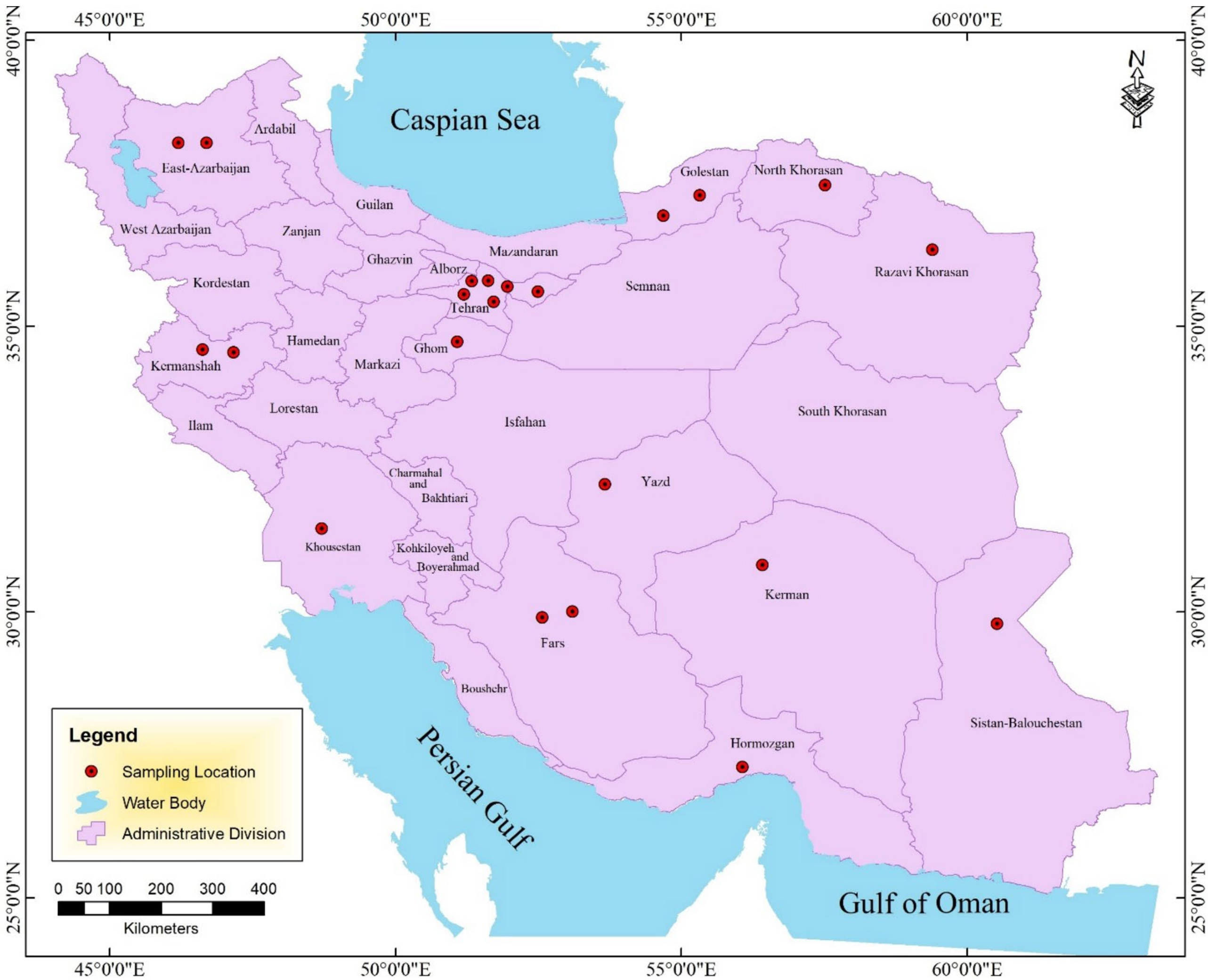

Fig. 1 Sampling locations. The map was prepared in a geographic information system (GIS) environment using ArcGIS version 10.2.2

Table 1 Interview guide

Guided questions
1. Based on your scientific and practical experiences in the field of providing safe water during natural disasters, what are the main strengths and weaknesses in our approach?
2. What are the primary challenges and obstacles in the process of ensuring water supply during emergency and disaster situations?
3. What solutions do you propose to prevent issues and address the challenges associated with managing safe water supply for disaster-affected populations?
4. What preparatory measures should be undertaken before the occurrence of natural disasters to enhance readiness and optimize the provision of safe water?
5. What actions should be implemented post-disaster to ensure the most effective provision of safe water for those affected by natural disasters?

Data analysis

The data were analyzed using Granheim and Lundman's qualitative content analysis method, which is widely applied in qualitative research for systematic text analysis [37]. This process involved transcribing interviews, reading texts for main ideas, identifying meaning units and initial codes, grouping similar codes, and uncovering underlying content. The transcribed data was then entered into MAXQDA 2020, reviewed multiple times by two independent researchers who identified and categorized codes based on similarity. Results were compared, and the process was refined through multiple iterations.

Rigor

To enhance the rigor of this study, we adopted Lincoln and Guba's (1985) trustworthiness criteria, which include transferability, dependability, credibility, and confirmability [37]. Transferability was ensured through a comprehensive description of the data collection, analysis, and outcomes, allowing readers to relate the findings to their own situations. Following the initial analysis, we shared the results with several participants to gather their final feedback. Furthermore, the final analysis was reviewed by additional field experts to confirm its validity from external viewpoints [38, 39]. Credibility was established through member and peer validation, prolonged engagement, and selecting participants with maximum diversity. For peer validation, two qualitative researchers verified the initial coding and categorization process.

Ethics approval and consent to participate

Participants were informed of the study's purpose, the voluntary nature of participation, and their right to withdraw at any time. Consent was obtained, and confidentiality was strictly maintained. Permission for note-taking and audio recording was secured, and audio files were erased after completion of the research. This study was approved by the Ethics Committee of Iran University of Medical Sciences under the ethics code IR.IUMS.REC.1402.009.

Table 2 Demographic characteristics of the study participants

Participant Number	korW experience (years)	Education Level / Job Title
Participant 1	5	PhD in Health in Disasters and Emergencies / University Professor
Participant 2	27	PhD in strategic management / University Professor
Participant 3	12	MSc in Occupational health engineering / Disaster Manager
Participant 4	28	Master of Water resource engineering / Natural Disaster Specialist
Participant 5	19	Master of Civil engineering / Disaster Specialist
Participant 6	24	General Physician / University Professor
Participant 7	15	MSc in Environmental health engineering / Disaster Manager
Participant 8	39	Master of Hydraulic Engineering / CEO of the Disaster Studies Company
Participant 9	28	Master of Laws / Health, Safety, and Environment Manager
Participant 10	25	PhD in Environmental health engineering / University Professor
Participant 11	11	Doctor of business Administration / Disaster Management Instructor
Participant 12	12	PhD in Health in Disasters and Emergencies / Disaster Specialist
Participant 13	20	PhD in Crisis Management / Disaster Manager
Participant 14	15	MSc in Nursing / Emergency Operation Center Manager
Participant 15	15	PhD in Health in Disasters and Emergencies / Emergency Manager
Participant 16	15	Doctor of Environment Engineering / Occupational Health Specialist
Participant 17	26	Master of Urban Design / Disaster Manager
Participant 18	20	PhD in Health in Disasters and Emergencies / Disaster Manager
Participant 19	23	Bachelor of emergency Management Operations / Emergency Manager
Participant 20	28	Bachelor of Civil engineering / Natural Disaster Specialist
Participant 21	10	PhD in Occupational health engineering / University Professor
Participant 22	25	Bachelor of Civil engineering / Disaster Manager

Results

In this study, 22 participants, all male and aged between 33 and 64 years, were included. Table 2 provides detailed characteristics of the participants, including their years of work experience, and educational backgrounds. This information is essential for understanding the diversity of expertise among the respondents, which contributes to the depth and reliability of the study's findings.

Following the comprehensive coding of the interviews, 509 initial codes were identified. Subsequent analysis and synthesis of these codes yielded 86 subcategories, 24 categories, and 4 themes. Table 3 presents the hierarchical structure of the findings, illustrating how raw data from interviews were systematically categorized into subcategories, categories, and themes. This table serves as a framework for understanding the key dimensions of drinking water supply management in natural disaster situations.

Prevention and reduction of water supply management challenges

Participants highlighted the importance of disaster risk assessment for water supply systems, focusing on six key components, with a primary emphasis on evaluating the impact of natural disasters on infrastructure. As Participant 7 mentioned, "In the event of a natural disaster, its impact on infrastructure should be assessed. However, we can simulate this beforehand to identify vulnerable areas and strengthen them, as proactive reinforcement is more cost-effective than post-disaster reconstruction." Understanding the entire system is equally important. Participant 21 highlighted the need to create detailed maps of the system, including wells, pumping stations, storage tanks, transmission lines, distribution networks, electrical distribution networks, communication systems, and computer systems. Furthermore, identifying the specific threats and hazards to the water supply system is crucial for effective disaster planning. As Participant 20 noted, "We need to identify the threats and hazards that could impact the water supply system. We must know which risks threaten our city or regions." Before an incident occurs, it is essential to identify all units and facilities, assess their weaknesses, and prepare for any vulnerabilities, as Participant 22 emphasized. Additionally, understanding the available water reserves and supply capacities, including human, managerial, and

Table 3 Themes, categories, and sub-categories obtained through qualitative content analysis

Themes	Main-categories	Sub-categories
Prevention and reduction of water supply management challenges	Risk assessment	Simulation of disaster effects
		Accurate understanding of the region climatic and water supply characteristics
		Hazard analysis
		Identification of vulnerabilities within the system components
		Analysis of structural, equipment, and human capacities
		Risk transfer
	Legal requirements and standards	Cultural awareness
		Determination of standards related to emergency water supply
		Legislation for optimized urban development
		Mandatory organizational regulations
		Community-oriented laws
	Control measures	Redundancy
		Proper design for emergency conditions
		Optimal site selection for water supply facilities and equipment
		Strengthening components of the water supply system against disasters
	Strengthening and optimization	Enhancing community resilience
		Improving resilience of the water supply system
Preparedness for an optimal response	Planning	Development of emergency water supply guidelines
		Prevention and mitigation plans
		Preparedness plans
		Development of emergency operation plans for optimal response
		Development of recovery and rehabilitation plans
	Coordination and organization	Organization of rescuers
		Improvement of intra-organizational and inter-organizational coordination
	Training and empowerment	Enhancing public risk awareness and knowledge
		Training water supply managers for emergency situations
		Optimizing training using various methods
	Financial resource management	Creation of financial resources
		Facilitation of financial payments for emergency situations
	Management of rapid response water rescue teams	Formation of specialized rapid response teams
		Capacity building and self-sufficiency of rapid response teams
		Updating information for rapid response team members
		Support for rapid response team members
	Management of machinery, equipment, and essential items for water rescue	Storage of essential items for machinery and equipment
		Needs assessment and stocking of necessary machinery and equipment
		Purchase and preparation of community-level crisis shelters
		Provision of equipment for quality monitoring, water treatment, water storage, and damage assessment

Table 3 (continued)

Themes	Main-categories	Sub-categories
	Development of infrastructures and systems for command	Enhancing system controllability
		Development of a suitable incident command system
		Improvement of command efficiency
		Facilitation of communication during emergencies
		Designation of a unit responsible for emergency water supply management
		Establishment of an Emergency Operations Center (EOC)
		Online monitoring of the system
	Emergency water storage	Identification of available water resources
		Creation of water resources
		Water storage at all community levels
		Identification and enhancement of local bottled water producers' capacity
	Assessment and needs assessment of water resources	Considering population characteristics in determining required water volume
		Understanding community behaviors regarding water shortages
		Necessity of determining the type of water supply for the public before a disaster
		Assessment of critical water-dependent facilities in the areas
		Estimation of the population requiring water in emergency conditions
		Development of a neighborhood-based water supply plan
	Facilitation of access to emergency water resources	Establishment of a network for temporary housing locations
		Minimizing waiting time for the public to receive water
		Identification of locations for emergency clean water extraction
		Optimal location of storage tanks and extraction valves
	Exercising	Optimizing drills through experience acquisition, realism, and repetition
		Conducting drills with community and designated rescue teams
		Drills to test facility performance
Reactive measures	Readiness and initial assessment	Declaration of emergency conditions and rapid assessment
		Issuance of readiness alerts at all levels and activation of emergency response plans
	Emergency training for the public	Education on water supply and purification methods through media
		Public education via emergency training teams
	Safety and security	Adherence to safety, health, and environmental standards
		Establishing security
	Protection of existing safe water resources	Preventing waste of available water
		Safeguarding accessible water resources
		Necessity of considering suitable locations for storing bottled water
		Utilization of clean and hygienic transfer and storage equipment
	Quality monitoring, emergency water purification, and facilitating access for those in need to safe water resources	Emergency purification of available water
		Distribution of purification equipment considering population dispersion
		Online monitoring of the system
		Facilitating access to water resources

Table 3 (continued)

Themes	Main-categories	Sub-categories
	Community-based initiatives	Management of volunteer assistance
		Utilization of water resources available to the public
		Building trust with disaster-affected individuals
Optimal recovery	Reconstruction	Rapid recovery of the system
		Job creation
		Increasing recovery speed
		Preserving water resources
	Knowledge management	Damage assessment with the aim of learning from incidents
		Management of lessons learned
	Sustainable development measures	Water supply management
		Emergency management

structural resources, is necessary for effective disaster preparedness, as stated by Participant 3. However, Participant 13 pointed out that some risks are unavoidable, adding, "Finally, there may be some risks that we cannot eliminate. In response to their effects, we must insure ourselves."

Participants stressed the need for legal and organizational measures to improve emergency water management, including granting government access to private machinery, revoking licenses from companies neglecting water storage, addressing misinformation, and ensuring continuity in crisis personnel and plans. As Participant 13 mentioned, "The next point is about management changes, which seriously disrupt crisis management plans. For example, there was an emergency water supply plan for the city of Tehran. I had personally prepared this draft, got it signed by the then-director of Tehran Province, and submitted it to the city council. However, with management changes, unfortunately, the issue lost traction and was eventually removed from the priority list."

Based on participant feedback, several control measures are critical to address high-priority hazards before disasters occur. These include ensuring redundancy for unique resources, incorporating hazard considerations into the design of water supply systems, strategically locating facilities and equipment, and reinforcing system components to withstand potential impacts. "Having parallel and backup pipelines is another solution that should be considered before disasters occur" (Participant 13).

Improving community resilience through public awareness of the impact of hazards on drinking water and strengthening the water supply system through network zoning were identified as essential actions before natural disasters. One participant emphasized the value of a zoned or ringed network, stating, "With a ring system, if one part of the network is damaged, the entire system doesn't fail. Although water pressure drops, it can mix with water from another unaffected zone, keeping the supply lines operational" (Participant 18).

Preparedness for an optimal response

Participants stressed the need for comprehensive planning to manage safe water supply during disasters, highlighting preventive strategies, continuity plans, preparedness initiatives, clear response roles, and post-crisis recovery plans. As Participant 3 mentioned, "The method of communication with the public should be considered, and the approach for informing them about how water will be supplied needs to be clearly defined." Improved coordination between organizations is crucial, with many highlighting the significant role of grassroots groups in disaster response. As Participant 4 noted, "We shouldn't forget about grassroots groups, like those that were returning from Arbaeen when the Kermanshah earthquake occurred. These groups immediately came to help the earthquake victims. These are all civil society organizations, and in some cases, the role of the government becomes less prominent."

According to the view of participants, training and capacity building at both community and organizational levels are crucial during the preparedness phase of disaster management. As noted by Participant 17 explained, "They asked me how we were able to suffer the least damage in the face of such a large flood. I told them that we acted like Prophet Noah. First, we raised people's awareness about the flood risk, then we gave them the warning, followed by informing them about the high-level warning. After that, we started taking physical measures to counter the flood in the area." In addition to this, Financial resource management in emergency situations for providing safe water requires identifying specific funding sources and establishing flexible payment processes distinct from normal circumstances. As Participant 10 mentioned, "We need a financial system and payment cycle for disasters in water supply management to ensure quick actions and payments without bureaucracy. This system should be specifically defined for emergency situations."

Participants emphasized the need to establish and empower specialized rapid response teams during the preparedness phase to ensure effective disaster response. They also stressed the importance of regularly updating the teams' information and providing both material and moral support. Participant 5 stated, "For rapid response teams, certain rewards should be considered to motivate them, ensuring that they will respond without complaints the next time a call for help is made." Additionally, Participant 14 noted, "Teams under the name 'Water and Sanitation (WatSan)' should be created and trained as part of rapid response teams to act specifically on ensuring the safety of available water during disasters." Similarly, managing machinery, equipment, and essential supplies is a critical aspect of disaster preparedness to ensure an effective response. Experts emphasized the importance of assessing needs, stockpiling general equipment like power generators, and specialized items like water purification systems. Additionally, consumable supplies, such as fuel and disinfectants, are essential for the operation of this machinery. As Participant 22 stated, "During the preparedness phase, we must stockpile everything that might be needed in an emergency. One of the most important supplies is for water purification and disinfection; for example, we need to have enough sodium hypochlorite stored for emergency situations. Fuel for machinery and consumable items for equipment are also essential needs that must be sufficiently stocked." Participants also highlighted key actions to improve incident command, including enhancing system controllability, real-time monitoring, and setting up an operations control center. They also emphasized developing an Incident Command System (ICS), training members, assigning a unified authority, and ensuring effective communication. These measures should be implemented before disasters and activated during the response phase. As Participant 4 noted, "A key aspect is secure and stable communication. Each neighborhood's crisis management base has a communication tower, built by Sarallah Headquarters, connected to HI Web and resistant to earthquakes up to 8 on the Richter scale. These towers ensure reliable communication." Participant 9 added, "The incident commander should be an individual or organization capable of coordinating all the people or response teams involved in water supply or scene management, ensuring they work together effectively."

Emergency water storage is crucial for disaster preparedness, and participants stressed the need to identify accessible water resources for both government and private sectors. They suggested developing water sources through artificial lakes and wells, based on regional potentials. Participants also emphasized encouraging both the public and organizations to store water, as well as supporting bottled water producers. As Participant 8 noted, "We suggested that, for example, we could install two shut-off valves on a 36-inch water pipeline. If something happens, these two valves can be closed, and it would then serve as a water supply source. We could also place a water tap there and provide water to the people from that point." Similarly, Participant 19 mentioned, "We can supply equipment that turns air into water before disasters and use them during disasters." Participant 2 also added, "We could even allocate parts of our reservoirs to bottled water production companies, allowing them to use it as storage during normal conditions. In critical situations, they could then provide it to us." Experts in this study also emphasized the need to consider factors such as local population consumption patterns, public behavior during water shortages, critical water-dependent facilities, and the number of people needing water to accurately determine emergency water requirements. Additionally, they suggested that water supply methods should align with community beliefs, and a neighborhood-based water supply plan should be developed. As Participant 12 noted, "One weakness is the lack of accurate predictions about water consumption due to cultural and belief differences, as priorities vary between individuals and regions, such as the importance of ablution, and needs differ between men and women." furthermore, Participants emphasized the importance of minimizing the waiting time for water access before a disaster by using methods such as increasing the number of water collection points, identifying extraction locations, optimizing reservoir and emergency water point placement, and creating a water network for designated shelter areas. These actions aim to ensure quick access to safe water for those affected. As Participant 6 pointed out, “We should have made the necessary predictions so that people in need can reach a suitable water source within a minute of walking. Additionally, we should increase the number of water extraction points to prevent many people from crowding a single source.”

Conducting realistic exercises, including joint drills with community groups and designated provinces, is essential. Optimizing these drills based on past experiences and performing functional tests for facilities can improve preparedness. As Participant 11 pointed out, “Look, the drills we conduct are not effective at all because they don’t resemble reality. A real drill would be for us to cut off the water supply in a specific area without prior notice, and then tell the emergency managers and staff to come and fix it. The managers and water supply emergency workers should face the situation unexpectedly and without prior warning.”

Reactive measures

After a disaster, emergency conditions must be declared, damage and needs rapidly assessed, and pre-developed response plans activated. Relief organizations should be mobilized accordingly. As Participant 1 stated, “The rapid assessment team should immediately go into the network and check for network damage.” Participant 8 added, “80% of the activities related to water supply in emergency situations should be carried out before disasters, while the remaining 20% involves activating our plans, issuing alerts, and making calls for action.”

Participants emphasized the need for public education on water provision and purification during disaster response. Some supported virtual education, while others stressed hands-on training by emergency teams. Participant 16 noted, “During disasters, we need to re-educate people on the proper ways to use water and access nearby water collection systems. Hands-on training by well-prepared teams is very effective for this purpose.” Participant 3 added, “One of the most important actions is media management, specifically determining which methods should be used to ensure water supply. Strategies for storing and disinfecting available water can all be communicated to the public through media channels.” Adhering to Health, Safety and Environment standards and ensuring security in disaster-affected areas are essential. As Participant 2 stated, “Security along the route for transporting equipment to the affected area and within the area itself should be provided by law enforcement.” Regarding water disinfection, Participant 18 emphasized, “For water disinfection, it’s better to distribute solid chlorine tablets to the public rather than liquid chlorine, as people may improperly pour liquid into water in inappropriate amounts. A better approach would be to give people chlorine tablets, instructing them to dissolve half of a tablet in, for example, 20 liters of water.”

Preserving clean water resources after disasters is also critical. This includes preventing water wastage, securing resources from vandals, selecting proper storage locations for packaged water, and using clean containers for distribution. Participant 9 stated, “Look, for transportation, we need to use suitable tankers that are specifically designed for carrying water, which have been disinfected in advance and have never been used for unsuitable materials or substances that produce odors.” Additionally, it is suggested that quality monitoring and emergency water purification be prioritized after disasters. Disinfection methods include boiling, using disinfection tablets, or alternative methods like lemon juice and salt, as explained by Participant 1: “In emergency situations, contaminated water can be disinfected using one or two spoons of lemon juice, salt, disinfectant tablets, boiling, or other methods.” Furthermore, installing water extraction points near affected houses was emphasized to ease access to clean water, as Participant 2 mentioned: “Since the inside of the houses was disorganized, we installed a water collection standpipe in front of each house, which helped reduce complaints.”

Community-based initiatives focus on leveraging community assets, such as managing volunteer aid, utilizing publicly available water resources, and building public trust through transparency. Participant 14 mentioned: “Bottles of mineral water were distributed in the form of household booklets. We recorded the distribution in these booklets to keep track of which households received the relief aid.”

Optimal recovery

Following the immediate response to the impacts of natural disasters, the reconstruction of the water supply system becomes a critical priority. Participants emphasized the importance of quickly restoring the system, ideally with the involvement of local communities. The recovery process must be completed as swiftly as possible, and water lines should only be reactivated after confirming that all leaks have been addressed to prevent contamination and wastage of available water resources. In the words of Participant 13, “For repairing and restoring damaged pipelines, we involved the local residents. In a way, we handed over the responsibility to them and paid them wages in return.”

The participants stressed the critical importance of assessing the damage caused by disasters to water supply systems and identifying their vulnerabilities. They also highlighted the necessity of documenting lessons learned and using them to improve safe water provision for disaster-affected populations. According to Participant 20, “Long-term actions should include evaluating system damages and prioritizing measures necessary to restore the water supply system to its normal state." Similarly, Participant 15 pointed out, "Our lessons learned are usually not recorded or documented anywhere. There is a need to categorize, organize, and make these experiences accessible."

Sustainable development actions focus on continuous improvement in managing safe water supply. Participants highlighted that these actions can be categorized into areas like expanding water supply networks to all regions and managing emergency situations through succession planning and disaster governance. As noted by Participant 22, "One of the essential actions we need to take is succession planning to increase the number of technical experts in water supply and management across the country. This ensures that we do not lose all technical specialists during emergencies and disasters." In addition, Participant 13 pointed out, "Having water supply networks in the country is an opportunity in itself—many places don't have this advantage."

Discussion

This research examines expert insights on water supply management for populations affected by natural disasters, aiming to identify key factors for its optimization. The findings indicate that safe water supply management in natural disasters requires a multidimensional and comprehensive approach, which can be explored through four main themes and twenty-four sub-categories. These themes, including "prevention and mitigation of water supply management challenges", "preparedness for crisis response", "reactive measures", and "optimal reconstruction", cover the key points in the safe water supply management cycle for disaster victims. All participants in this study were male, reflecting the gender imbalance in Iran's water supply and disaster management sectors. This aligns with broader trends in STEM and emergency response fields, where cultural and institutional barriers often limit women's participation [40]. Addressing this gap is crucial for diversifying perspectives and improving disaster management strategies.

Prevention and reduction of water supply management challenges

Effective prevention and reduction of water supply challenges require a combination of regulatory measures, risk management, and sustainable planning. The findings of this study are consistent with prior research highlighting the critical role of disaster risk management in reducing vulnerabilities [14, 41], establishing enforceable standards for safe water access to protect public health [1, 42], and implementing regulations to balance water extraction with sustainable urban development [15, 43]. However, participants pointed out the need for regulations such as the non-transfer of personnel involved in crisis management and ensuring that managerial changes do not impact disaster management programs within organizations, which had not been addressed in previous studies.

Strengthening infrastructure and building redundancy are critical strategies for enhancing system resilience and mitigating disaster impacts. Consistent with prior studies [21, 44], this study underscores the importance of reinforcing critical infrastructure—such as pipelines, storage facilities, and treatment plants—and implementing redundancy measures to enhance system resilience. These measures are grounded in the principles of disaster risk reduction and sustainable water resource management, which advocate for proactive planning, adaptive capacity, and community engagement to mitigate the impacts of extreme events and ensure long-term resource sustainability [45, 46].

Preparedness for an optimal response

Effective disaster response requires robust coordination among institutions to prevent redundant efforts and ensure efficient resource allocation. According to the findings of this study, implementing a set of actions related to infrastructure and management preparedness is crucial for effectively responding to the effects of natural disasters. Consistent with the results of this study, coordination between various institutions is recognized as one of the key factors for successful crisis management [17, 21], which can help prevent parallel activities among different organizations during emergencies.

Public education and financial mechanisms are critical components of disaster preparedness. Various studies [5, 17] have shown that public disaster preparedness through general and specialized education can significantly improve responses to disasters, which is well reflected in the "Training and Empowerment" category of this research. Another important preparedness activity for an optimal response is the establishment of a financial support mechanism for emergency situations [47], which was also emphasized by the participants in this study. In emergency situations, delays in payment to suppliers can lead to a lack of cooperation from them.

Innovative solutions and context-specific planning are essential for effective disaster management. This study also reinforces several critical disaster preparedness aspects including the importance of developing comprehensive programs [21, 44, 48], the need for training and empowering specialized rapid response teams [21], securing essential machinery and supplies for emergency use [14], creating a command system and defining roles and responsibilities during disasters [49], and conducting exercises based on all possible scenarios [15]. However, participants, based on their experiences, mentioned actions that were not highlighted in previous research findings. For example, participants identified the installation of water extraction taps in high-diameter transmission lines as a method for creating water sources for emergency situations. In the event of a disaster and the failure of the water supply system, these transmission lines could be used as underground water reservoirs. Furthermore, another preparedness measure that had not been widely addressed in previous research but was emphasized by participants in this study is that the specific water needs during emergencies and the type of water supply should be determined based on the consumption, cultural, and religious characteristics of the people in different regions. Failing to consider these factors when determining the amount of water and the method of water distribution may lead to dissatisfaction among disaster victims. This is because people in a region may be more religious and require more water, or they may prefer local water sources over bottled water. These findings underscore the importance of context-specific planning in disaster management, ensuring that response strategies are both effective and culturally sensitive.

Reactive measures

Effective post-disaster response requires rapid assessment, public education, and protection of existing water resources to ensure timely and efficient relief efforts. The findings of this study highlight the critical importance of conducting rapid and accurate post-disaster assessments to evaluate damage to water supply systems and identify immediate needs. Such assessments are essential for allocating resources effectively and avoiding the deployment of unnecessary or insufficient relief equipment [18]. This is because, without such an assessment, relief equipment may be sent to the area that is unnecessary, or the amount of water sent may be insufficient for the actual needs. Previous studies have emphasized the importance of this action [11]. Participants emphasized the need for widespread public education on emergency water purification methods, a strategy supported by a research, which demonstrated that such interventions can significantly reduce the incidence of waterborne diseases in disaster-affected areas [8, 16]. Such training can empower communities to address immediate water needs and prevent waterborne diseases, which are a leading cause of morbidity in disaster-affected areas [12, 24, 50]. Media-based education is a cost-effective strategy for disseminating critical information quickly, particularly in resource-constrained settings. Studies have shown that such interventions can significantly reduce the incidence of waterborne diseases by promoting safe water practices [12, 51]. This issue has not been extensively addressed in previous studies on water supply management. Prior studies [17, 21, 41] and the participants in this study underscore the importance of safeguarding existing water resources during disasters. Protecting drinking water resources from contamination and overuse is critical for ensuring a reliable supply of safe water throughout the recovery process [2, 12, 52].

Optimal recovery

Community participation and sustainable reconstruction are key to effective disaster recovery, ensuring long-term resilience and improved performance compared to pre-disaster conditions [6]. One gap identified in previous studies was the lack of active community participation throughout all stages of disaster management. The findings of this study introduced community-based actions as one of the influential factors in the optimal management of safe water supply for disaster victims, highlighting that providing safe water is not only achievable through technical measures but also requires the active participation of the community. While previous studies have acknowledged the theoretical importance of community participation, practical implementation strategies have been largely overlooked, a gap that this study seeks to address [20, 53]. In alignment with the emphasis on utilizing lessons learned from disasters as discussed in the book Resilient Cities [54], this study revealed that the knowledge gained from disasters, particularly regarding their impact on water supply systems, should be managed and used effectively. Disasters, alongside their harmful effects and costs, practically highlight the vulnerabilities of communities, and these weaknesses should be identified and addressed by urban managers [55]. The use of sustainable methods for rebuilding and improving infrastructure not only reduces the impacts of crises but also lowers the likelihood of similar problems occurring in the future [7, 19]. This finding aligns with studies that emphasize the importance of sustainable measures in reconstruction [56]. The concept of Build Back Better, proposed by the United Nations, stresses that reconstruction should lead to the improvement of community performance compared to the pre-disaster state. This includes both structural and non-structural measures such as revising urban plans and economic reconstruction [57].

Conclusion

This study identifies critical factors for enhancing emergency water supply during natural disasters, emphasizing the necessity of a comprehensive and multidimensional approach. Access to safe drinking water is a fundamental human need, particularly in emergency situations, and the study highlights the urgent necessity of being well-prepared to meet this need. Effective coordination between various organizations and institutions, as well as the efficient management of available resources, is essential for ensuring that clean water is accessible in disaster-stricken areas.

One of the key contributions of this study is its focus on innovative measures that have been less emphasized in previous research. For example, the installation of water extraction taps along transmission lines offers a proactive solution to water distribution, ensuring that water can be accessed from various points even if parts of the network are damaged. This approach helps to reduce the reliance on centralized systems and can significantly enhance the resilience of water supply networks in crisis situations. Furthermore, the study highlights the importance of considering local cultural, religious, and consumption characteristics when estimating water needs during a disaster. These factors play a crucial role in determining not only the quantity of water required but also the type of water supply methods that would be most effective. Understanding the diverse needs of communities allows for tailored responses that are more likely to be accepted and utilized, thereby improving the overall effectiveness of emergency water supply strategies. In addition to these innovative measures, the research underscores the importance of active community participation in disaster preparedness and response. The involvement of local communities in water management not only ensures better access to safe water but also strengthens the overall crisis management process. As demonstrated in this study, community-based approaches can significantly enhance the efficiency of water supply efforts and help build resilience in the face of future disasters.

Overall, these findings provide critical insights for policymakers and water resource managers to formulate evidence-based regulations and targeted capacity-building programs, enhancing disaster preparedness and response. By integrating these strategies, water supply systems can be strengthened to ensure resilience, redundancy, and adaptability in the face of complex and evolving disaster scenarios.

However, this study has some limitations. One of the main limitations of this study is that, due to the qualitative nature of the research method, the findings may be subject to subjective interpretations and cannot be widely generalized. Therefore, it is recommended that broader quantitative studies be conducted to validate the qualitative findings. Another limitation of the study is its focus on Iran, and further research in other countries or regions is needed to examine potential differences and similarities. Furthermore, this study suggests that future research on safe water provision in natural disasters should be region-specific, taking into account all natural hazards, the status of water resources, existing capacities, and vulnerabilities within each area. Additionally, a limitation of this study is the lack of female representation among participants. This was not due to intentional exclusion but rather the current workforce composition in Iran, where technical and managerial roles in water supply and disaster management are predominantly held by men. However, we acknowledge this as a limitation, and if possible, future research could incorporate female perspectives to ensure a more comprehensive understanding of the subject.

Abbreviations

UNDRR	United nations office for disaster risk reduction
WEAP	Water evaluation and planning
MCDM	Multi-criteria decision-making
AHP	Analytic hierarchy process
PROMETHEE V	Preference ranking organization method for enrichment evaluations
ERP	Emergency response plan
CWS	Community water systems
QCA	Qualitative content analysis
GIS	Geographic information system
ICS	Incident command system
EOC	Emergency operations center
WatSan	Water and sanitation

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Author contributions
The contributions of the authors are as follows: Seyed Hesam Seyedin was responsible for the conceptualization and project administration, as well as the supervision and validation of the study. Saeid Bahramzadeh Gendeshmin contributed to data curation, formal analysis, methodology, funding acquisition, and software management, as well as writing the original draft and reviewing and editing the manuscript. Mohsen Dowlati participated in formal analysis, investigation, resources, supervision, and validation, and contributed to the review and editing of the manuscript.

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Data availability
All data generated during this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
This manuscript is based on a Ph.D. thesis in the field of health in disasters and emergencies and has received ethical approval under the code IR.IUMS.REC.1402.009 from the Research Ethics Committee of Iran University of Medical Sciences. The study adhered to the principles outlined in the Declaration of Helsinki and the Committee on Publication Ethics (COPE). To ensure ethical compliance, participants were fully informed about the study's objectives and procedures, and their informed consent was obtained. Participation was entirely voluntary, with the option for participants to withdraw at any time. To protect anonymity, participants were assigned codes, and no identifying information was recorded or disclosed during the interviews. Audio recordings of the interviews were permanently deleted after transcription. Confidentiality was upheld throughout all stages of the research, from data collection to publication.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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