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Drinking water resources criteria in emergencies and disasters: A systematic literature review

Aman Allah Zamani[1], **Hamid Reza Abbasi**[2*], **Vali Alipour**[3], **Mahmoudreza Peyravi**[4], **Payam Shojaei**[5], **Ali Goli**[6], **Leila Mohammadinia**[7]

[1]Health Human Resources Research Center, Department of Health in Disasters and Emergencies, School of Management and Information Sciences, Shiraz University of Medical Sciences, Shiraz, Iran
[2]Trauma Research Center, Shahid Rajaee (Emtiaz) Trauma Hospital, Shiraz University of Medical Sciences, Shiraz, Iran
[3]Environmental Health Engineering, School of Health, Hormozgan University of Medical Sciences, Bandar Abbas, Iran
[4]Department of Health in Disasters and Emergencies, Health Human Resources Research Center, School of Management and Medical Informatics, Shiraz University of Medical Sciences, Shiraz, Iran
[5]Department of Management, Shiraz University, Shiraz, Iran
[6]Department of Sociology and Social planning, Shiraz University, Shiraz, Iran
[7]Department of Health Policy and Management, School of Management and Medical Informatics, Tabriz University of Medical Sciences, Tabriz, Iran

Abstract
Background: Disasters occur unexpectedly each year, killing thousands around the world. Millions are directly under the influence of the outcomes of these events and their survival depends on the immediate state and international aid. This supports should be obtained in early hours after disasters. The main important need after disasters is safe water supply, which along with providing shelter, medicine, and nutrition, is vital to prevent diseases. So, immediate actions are needed to replace suitable drinking water resources for affected people.
Methods: This study was conducted in 2019 using Web of Science, PupMed, Springer, Scopus, Embase databases (from 2000 to 31 September 2019). The PRISMA guideline was used to compile the study. All articles included in this study were original articles, short communications, letters to editor, editorials, systematic reviews, and articles presented at conferences and international congresses on the main topic of the study. Only English full-text articles were included in this study.
Results: According to the results, water resources supply in disasters and emergencies criteria were classified into 4 main and 30 sub-criteria. The main criteria include environmental, economic, technology performance, quantitative and qualitative characteristics of water resources, which have 4, 2, 12, and 12 sub-criteria, respectively.
Conclusion: This study intends to assist disaster service officials and decision makers and supervisors to plan for drinking water supply from area water resources, before the disaster and based on the history and geographical characteristics of the area, to take actions and meet the drinking water needs of the region.
Keywords: Disaster, Emergency, Drinking water, Criteria
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***Correspondence to:**
Hamid Reza Abbasi,
Email: abbasimezy@gmail.com

Introduction

Disasters are unexpected and often sudden events that cause harm, destruction, human suffering, disrupt local capacities, and require national or international assistance (1). Disasters occur unexpectedly each year, killing thousands around the world. Millions are directly under the influence of the outcomes of these events and their survival depends on the immediate state and international aid. This supports should be obtained in early hours after disasters (2).

In the last two decades alone (2018-1999), 8202 natural disasters have occurred in the world. 1.3 million people were killed during this period, and the number of affected population was about 4 billion (3). The main important need after disasters is safe water supply, which along with providing shelter, medicine, and nutrition, is vital to prevent diseases (4). So, immediate actions are needed to replace suitable drinking water resource for affected people (5). Safe drinking water supply is a serious problem for many human societies, especially in developing countries and arid regions (6). In these areas, due to the lack of drinking water supply systems, unsafe water including surface resources such as rivers and lakes are used. Meanwhile, water resources pollution, poor management, and failure to follow strict planning instructions, intensify these disasters that can put vulnerable people, especially children and infants, at risk of death (7). More than 60% of the world's children die from infectious and parasitic diseases, which are mainly related to water. According to the report of the World Health Organization (WHO), water-borne diseases are the main cause of death among children (under 5 years) in the world, hence, every 20 seconds, a child dies from water-related diseases (8). Therefore, accessibility to clean water guarantees the community health. The WHO reported that 71% of the world's population (55% rural and 85% urban population) have access to healthy water (9). Disasters has a significant effect on infrastructures. In this critical conditions, providing services is very hard (10). In disasters, water infrastructure may be damaged or destroyed or the water distribution network may be disordered. Transporting water from other regions due to the possibility of highway damage may not be desirable. Long transportation time has high costs and is unacceptable (11).

Disasters like floods, may significantly enhance the microbial content in water resources (12), causing salinity, releasing hazardous substances, and increasing turbidity (13). This shows water compounds complication as a result of disasters. Excessive water contamination, causes failure in conventional water treatment. Heavy rains may cause a significant increase in dissolved organic carbon (14), leading to the dissolution of heavy metals (15) and the formation of disinfection by-products (16), and taste problems during disinfection with chlorine compounds.

In emergencies and disasters, the water resources available for sanitary purposes, drinking and cooking are very limited. Therefore, it is necessary to consider appropriate volume of water to prevent the occurrence of diseases (8). In most studies, providing drinking water to the affected area are from bottled water or moving water by tanker from other areas. While the best way to provide safe water in disasters is to use available resources in disaster area so, if recovery phase is prolonged, there will be no problem with drinking water supply. The purpose of this study was to identify and select appropriate and effective criteria and factors for drinking water resources supply in emergencies and disasters.

Materials and Methods

This study was conducted in 2019 using Web of Science, PupMed, Springer, Scopus, Embase databases. The PRISMA guideline (17) was used to compile the study. Table 1 shows the search strategies used in different databases.

Inclusion/exclusion criteria of the study articles are as follows:

Inclusion criteria: All articles including original articles, short communications, letters to editor, editorials, systematic reviews, and articles presented at conferences and international congresses on the main topic of the study. Only English full-text articles, which were published between 2000 and September 31, 2019, were included in the study.

Exclusion criteria: Duplicated articles from databases with insufficient reporting of data in article text and unrelated title and article text were excluded.

Extraction of the articles from the study were done in three stages (identification, screening, and eligibility). In the identification stage, after searching the desired databases and using article references (snowball method), 17 341 articles were identified. In the screening phase, duplicate articles (2,175 articles) were excluded. In the eligibility stage, after reviewing the abstracts, 14,522 unrelated articles were excluded and 644 articles were reviewed in full text, and finally, 17 related articles were included in the study. The PRISMA (17) and STROBE (18) checklists were used to evaluate articles. Figure 1 shows the complete process of reviewing the collection of study articles and the method of analysis.

Results

After searching in valid databases and article references, 17 341 articles were received. With applying the exclusion criteria among initial searches, and reviewing by content

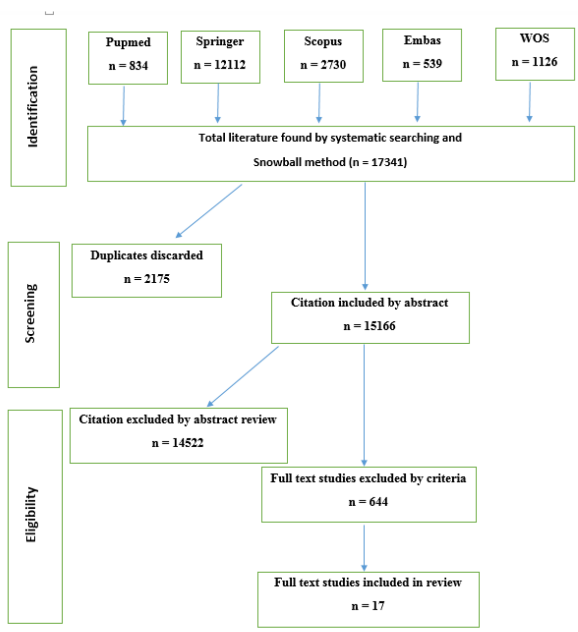

Figure 1. The process of selecting articles in the study.

Table 1. Search strategies in databases

Databases	Search Keywords	Total/Related Article
PubMed	(("Disasters"[Majr] OR "Emergency"[Title/Abstract] OR "Crises"[Title/Abstract] OR "Humanitarian"[Title/Abstract]) AND ("Water"[Majr] OR "drinking water"[Title/Abstract]))	834/146
Scopus	(TITLE (("Disaster" OR "Emergency" OR "Crises" OR "Humanitarian")) AND TITLE-ABS-KEY ("Water" OR "drinking water"))	2730/145
Embase	('disaster':ti OR 'emergency':ti OR crises:ti OR humanitarian:ti) AND ('water':ab,ti OR 'drinking water':ab,ti)	539/35
WOS (Web Of Science)	TITLE: ("Disaster" OR "Emergency" OR "Crises" OR "humanitarian") AND TOPIC: ("Water" OR "drinking water")	1126/105
Springer	(Disaster OR emergency OR crises OR humanitarian) AND (water OR water drinking)	12112/203

analysis to identify the criteria for selecting drinking water resources in emergencies and disasters, 16 articles related to the research purpose were included in the study. Figure 1 shows the process of selecting related articles in the study. Table 2 shows the characteristics of the articles, objectives, and specialized techniques used to identify important criteria for selecting drinking water resources in emergencies and disasters. The results show that water resources supply in disasters and emergencies criteria were classified into 4 main and 30 sub-criteria. The main criteria include environmental, economic, technology performance, quantitative and qualitative characteristics of water resources, which have 4, 2, 12, and 12 sub-criteria, respectively (Table 3).

Discussion

In most studies, specific main water resources supply criteria in emergencies and disasters have been considered. In the studies by Sadr et al (25), Golfam et al (28), and Butler and Silva (24), only in terms of performance criteria, and in the studies by Vitello et al (11), De Buck et al (30), Ray (32), Bross et al (31), Brown et al (29), and Jeihouni et al (33), only water resources characteristics criteria have been used. Some studies by Pagsuyoin et al (19), Santos et al (20), Qu et al (26), Qu et al (27), Loo et al (21), Yekta et al (22), and Qu et al (23) also used two or three main criteria (economic, environmental, and technology performance criteria with the limitation of sub-criteria). Given the importance of environmental health aspects, it is necessary to pay more attention to the criteria for drinking water supply in disasters and emergencies that has been ignored. In this study, in addition to sub-criteria of technical, economic, environmental, and water resources characteristics for drinking water supply in disasters and emergencies, environmental health and hygiene aspects have also been considered.

Environmental criteria

Environmental criteria are often ignored or less emphasized for water treatment systems. Product or process of environmental constancy transactions take place based on the sense that the benefits against the negative effects on the environment are measured. Environmental constancy must consider production perspective (raw materials), operation and final disposal.

The most important environmental sub-criteria in drinking water supply in disasters and emergencies studies include residual by-product and environmental impact (19-23), the need for raw materials (19), but in this study, very important sub-criterion adaptability to health policy (22) has also been considered.

Economic criteria

Economic efficiency is right price measurement that is designated by various market vigor's. Analyzing relevancy between these driving forces is complicated, because the cost of technology is not the only important factor in the equation (19).

The sub-criteria considered in this economic criterion are capital cost (21,22,24) and operation and maintenance cost (22, 25-27). In operation and maintenance cost criteria, costs associated with labor, materials (e.g., equipment upgrades and membrane replacement), energy, and chemicals are considered (25).

Technological performance

This main criterion points to the technology capacity for obtaining its core performance (water purification), ideally with the least amount of resources. This may be the most important criterion for assessing durability (19). The technological performance main criterion has 12 sub-criteria. The most important sub-criteria include production capacity (24), adaptability (25), ease of deployment (21, 25-27), land requirement (25), level of complexity (25), performance (21), operations and maintenance (24), energy consumption (19-21, 25-27), ease of use (19-21, 27), material supply chain (19-21, 24, 28), and technical maturity (23, 26). However, due to the great importance of health policies and environmental health aspects, the heavy metal removal rate sub-criterion (24) has also been considered in this study.

Quantitative and qualitative characteristics of water resources

The quantity and quality of drinking water is one of the most important public health issues in emergencies and disasters. In normal situations, microbial contamination of drinking water is more dangerous to health than

Table 2. Description of the included articles on drinking water resources criteria in emergencies and disasters

Author/Year/Country	Type	Methodology	Study Objective
Sadr et al, 2015, UK	Original research	Multi-criteria analysis (MCA)	Selection of technology for water reuse in different cases
Vitello et al, 2009, USA	Original research	Project	Mobile water disinfection system in emergencies and disaster
Pagsuyoin et al, 2015, Philippine	Original research	TOPSIS	Prioritization of on-site water treatment technology
Santos et al, 2015, Philippine	Original research	AHP, TOPSIS	Use of decision-making techniques to supply water on site
Qu et al, 2015, China	Original research	AHP	Building an evaluation system to treat contaminated resources
Buck et al, 2015, Belgium	Systematic review	Search in databases	Improving health indicators in disasters
Santos et al, 2016, China	Original research	Fuzzy TOPSIS, AHP	The most suitable water treatment technology in emergencies and disasters
Loo et al, 2012, Singapore	Review	Multi-criteria analysis	Technical criteria for selecting water resources in emergencies and disasters
Ray et al, 013 USA	Original research	Project	Low-cost water treatment technologies in disasters
Yekta et al, 2015, Iran	Original research	Multi-criteria group decision making	Evaluation of available water supply options in Qom
Bross et al, 2019, Germany, Austria	Literature review	Searching SCOPUS database	Disaster management planning and emergency water supply
Qu et al, 2016, China	Original research	TOPSIS	Water treatment options in water pollution incidents
Butler and Silva, 2013, USA	Original research	Cost model	Weighting of technical criteria for water supply in the site of membrane technologies
Golfam et al, 2019, Iran	Original research	AHP, TOPSIS	Reducing the negative effects of climate change on water supply
Jeihouni et al, 2015, Iran	Original research	GIS, AHP, SDSS	Water resources management in drought crisis

contamination caused by chemical compounds, except in special cases, such as the entry of chemicals into the surface of the water source (8).

The quantitative and qualitative characteristics of water resources main criteria has 12 sub-criteria. The most important sub-criteria in the studies include total coliform (11, 29-33), *E. coli* (11, 29-33), pH (11, 31-33), total dissolved solids (TDS) (11, 32, 33), turbidity (11, 32, 33), electrical conductivity (32, 33), nitrate (32, 33), and hardness (32, 33). In this study, general characteristics of water resources such as distance to water source (29) and water needs based on land use (residential, health, commercial, educational, etc.) have been also considered (29-31).

Disasters are associated with increased morbidity and mortality due to communicable (34) and health challenges-related diseases (35). Since more than 25% of the disease burden occurring in emergencies and disasters are attributed to environmental risk factors (36), providing the necessary infrastructure for the proper implementation of the response plan in the event of a disaster is necessary and inevitable. The minimum needs of the people affected must be met by using the facilities and capacity of the region.

In the past, drinking water supply in affected areas was concentrated in the form of bottled water or by transferring water by tankers from different areas (21), which due to the possibility of a long recovery phase, the need for safe water in the affected area is not fully met and causes health problems. Therefore, the use of water resources in the affected area is more practical and sustainable (37). Factors such as available water quantity, water supply network reliability, equal access of people to water, raw water quality, potential pollutants, water source protection strategies, treatment processes required for rapid provision of safe drinking water, water acceptability and considerations, as well as epidemiology in disaster-affected areas should be considered (8).

Due to the importance of safe water supply in emergencies and disasters and the need for planning in

Table 3. The main criteria and sub-criteria of drinking water resources in emergencies and disasters

Criteria	Sub-criteria	References
Environmental	Need for raw materials	Pagsuyoin et al (19)
	Residual by-product and environmental impact	Pagsuyoin et al (19), Santos et al (20), Loo et al (21), Yekta et al (22) Qu et al (23)
	Adaptability to health policy	Yekta et al (22)
	Social acceptance	Pagsuyoin et al (19) , Loo et al (21)
Economic	Capital cost	Loo et al (21), Yekta et al (22), Butler and Silva (24)
	Operation and maintenance cost	Yekta et al (22), Sadr et al (25), Qu et al (26), Qu et al (27)
Technological performance	Production capacity	Butler and Silva (24)
	Adaptability	Sadr et al (25)
	Ease of deployment	Loo et al (21), Sadr et al (25), Qu et al (26), Qu et al (27)
	Land requirement	Sadr et al (25)
	Level of complexity	Sadr et al (25)
	Performance efficiency	Loo et al (21)
	Operations and maintenance	Butler and Silva (24)
	Energy consumption	Pagsuyoin et al (19), Santos et al (20), Loo et al (21), Sadr et al (25), Qu et al (26), Qu et al (27)
	Ease of use	Pagsuyoin et al (19), Santos et al (20), Loo et al (21), Qu et al (27)
	Material supply chain	Pagsuyoin et al(19), Santos et al(20), Loo et al (21), Butler and Silva (24), Golfam et al (28)
	Technical maturity	Qu et al (23), Qu et al (26)
	Heavy metal removal rate	Butler and Silva (24)
Quantitative and qualitative characteristics of water resources	Water demand based on land use	Brown et al (29), De Buck et al (30), Bross et al (31)
	Distance to water source	Brown et al (29)
	Total coliform	Brown et al (29), Bross et al (31), Vitello et al (11), Ray et al (32), Jeihouni et al (33)
	E. coli	Brown et al (29), Bross et al (31), Vitello et al (11), Ray et al (32), Jeihouni et al (33)
	pH	Bross et al (31), Vitello et al (11), Ray et al (32), Jeihouni et al (33)
	Total soluble solids (TDS)	Vitello et al (11), Ray et al (32), Jeihouni et al (33)
	Turbidity	Vitello et al (11), Ray et al (32), Jeihouni et al (33)
	Electrical conductivity	Ray et al (32), Jeihouni et al (33)
	Nitrate	Ray et al (32), Jeihouni et al (33)
	Hardness	Ray et al (32), Jeihouni et al (33)
	Sulfate	Ray et al (32), Jeihouni et al (33)
	Temperature	Ray et al (32)

this regard, it is recommended that a questionnaire and checklist of drinking water supply criteria in disasters must be designed, and criteria's weighting based on the opinion of experts and planning for drinking water supply should be done based on the disaster type before occurrence.

The lack of access to some international literature was the main limitation of this study. There was only the possibility to check English literature and the authors had no knowledge on what has been written in other languages such as Japanese or Chinese, etc.

Conclusion

In the present study, effective criteria and sub-criteria in the selection of drinking water resources in emergencies and disasters are presented. In this study, 17 final articles were included and reviewed. The most important main criteria include environmental, economic, technological performance and the criteria of quantitative and qualitative characteristics of water resources, and attempts were made to use the most effective criteria to play a role in selecting water resources. This study intends to assist disaster service officials and decision makers to plan for drinking water supply, before disaster occurrence and based on history and area geographical characteristics and water sources in region.

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Ethical issues

In this article, the authors considered all the ethical points in collecting data and certify that this manuscript is the original work of the authors, and all data collected during the study are as presented in the manuscript, and no data from the study has been or will be published elsewhere separately. This article was extracted from a PhD thesis approved by the Ethics Committee of Shiraz University of Medical Sciences (Ethical code: IR.sums.rec.1398.1322).

Competing interests

The authors declare that there is no conflict of interests.

Authors' contributions

Study concept and design were performed by AA, HA, and VA. Formulation of research question and selection criteria was performed by AA, HA, VA, and MP. Search strategy was performed by AA, HA, VA, MP, PS, AG, and LM. The literature search and study selection were performed by AA, HA, VA, MP, PS, AG, and LM. The data analysis was performed by AA, HA, VA, MP, PS, AG, and LM. The manuscript was written by AA, HA, VA, MP, PS, AG, and LM. The study supervision was performed by AA and HA.

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