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Risk assessment of drinking water supply and distribution system of Zanjan City from Tahm dam using water safety plan

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ABSTRACT

Sufficient and good quality drinking water has always been one of the needs of humans. The present study was conducted to evaluate the risk of drinking water supply and distribution systems in Zanjan City from the Tahm dam by implementing water safety plan (WSP) in 2019. This descriptive cross-sectional study was performed using the WSP-QA tool and the World Health Organization's (WHO) and the International Water Association's WSP. First, the checklists were completed and water company experts were interviewed and, then, the data were analyzed by the data tool, and the most significant hazards were identified by the experts. This companies staff prioritized using the risk analysis matrix provided by WHO. The results showed that 325 points were obtained from the 440 total scores of full implementation of the WSP. That showed 73.86% in accordance with implementation with WSP. Risk assessment results showed that rural sewage discharge in the catchment area, low consumer knowledge, and Old pipes and aging water infrastructure were the three most prioritized important hazards of the studied water supply systems. In general, the results of the WSP-QA tool implementation demonstrated that the water supply system of Zanjan City from Tahm dam was in an average condition. Based on the risk assessment of the findings of this water system in the catchment area and the endpoint of use, more attention should be paid to the weaknesses and strengths.

Keywords: Drinking water; Water safety plan; Risk assessment; Zanjan City; Tahm dam

1. Introduction

Access to safe drinking water is an essential and fundamental human right. Providing clean water is a necessity for community health, lifestyle promotion, environmental protection, economic activity, and development. Lack of access to safe drinking water in both quantitative and qualitative terms can cause and spread waterborne diseases [1,2]. Access to safe water and improved health can reduce about 9.1% of diseases and 6.3% of deaths worldwide [3].

Providing safe drinking water is essential to prevent waterborne diseases. However, monitoring and maintaining safe water in the world's water supply and drainage systems is a challenge. Diseases caused by inappropriate drinking water are estimated to kill 502,000 people/y [1]. Since 1990, two billion people have access to drinking water; however, according to the 2017 World Health Organization (WHO) report, 780 million people worldwide have restricted access to drinking water [4].

Having water with high quality and quantity is the basis for sustainable development and health of every society [5]. A common way for controlling the quality of drinking water is to control it at the usage point. However, since there are

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concerns about the occurrence of physical, microbial, and chemical contamination in the drinking water supply systems or the improper functioning of the processes used to sanitize the water, WHO has established water safety plan (WSP) to address such problems [6,7]. The most effective way to ensure sustainable safety of a drinking water supply system is to use comprehensive risk assessment and management in the WSP approach that covers all the stages of water supply from catchments to consumers [7]. Water safety management, as outlined by sustainable development goals, can develop WSP, risk assessment, and risk management approaches introduced by WHO, as implemented in 93 countries around the world [8].

WSP provides a systematic approach to ensure the quality and safety of distributed water and covers all the stages of water supply from the catchments to the consumption points. The purpose of the drinking WSP is to ensure the quality of drinking water based on risk management that emphasizes the prevention of pollution in drinking water sources, treatment of water to reduce or eliminate pollution to meet standards, as well as prevention of water contamination during storage, distribution, and consumption [7]. The principles and concepts of WSP are inherently flexible and fully adapted to local conditions, which can be applied to assure water safety across a wide range of system types and sizes as well as levels of resources. Despite the natural challenges, nearly three-quarters of the countries that implement WSPs do so in rural areas, which indicates that WSPs can meet the needs with limited resources [9].

Zanjan City is located at 48°55′ to 47°40′ east longitude of Greenwich meridian and 37°15′ to 36° and 25′ north latitude of the equator. This city has two sources of surface and underground water supply and, in this study, the surface water source of Tahm dam was examined. Tahm dam is located 15 km northwest of Zanjan City and 8 km downstream of Tahm village at the altitude of about 1,900 m above sea level (Fig. 1) and the artificial lake. It has created an area of 317 ha, which provides drinking water to 40% (180,000 people) of Zanjan City [10]. The water loss rate in the system was 23% last year. Implementation of WSP by Zanjan City Water Company started in 2016 and covered 100% of the population and the entire water supply system was under development [11].

The purpose of the present study was to determine the status of WSP implementation in Zanjan City water supply and distribution system from the Tahm dam and evaluates its risk factors.

2. Materials and methods

The study was carried out to determine Zanjan City drinking water supply and distribution system from Tahm dam safety in two phases:

2.1. WSP quality assurance tool (WSP QA tool)

WSP implementation has started in Zanjan City since 2017; thus, the checklists and questions of the WSP-QA

Fig. 1. Study area location in Iran and Zanjan (Adapted from Najafi et al. [10]).

tool (ver. 2010) were completed with the study population consisting of the water supply system and companies, organizations, and individuals involved in the supply and distribution of drinking water in Zanjan City experts and WSP team member based on 2019 documented information and local visit. These instruments were used in the previous study by Gholami et al. [12].

2.2. Risk assessment

In order to assess the risk and identify the most important hazards of the studied water supply system based on WHO guidelines [13], a questionnaire on the risk analysis of drinking water supply systems was employed, the validity and reliability of which were previously reported in Ardebil water supply system using correlation coefficient (r = 0.87) [14]. Prioritization of risky events could be scored through this method in all the four major components of the water supply system: catchments, treatment, distribution system, and consumption points [15] via conducting interviews with regional WSP team members. Different approaches have been presented for risk ranking. In this study, a semi-quantitative 5 × 5 risk matrix, derived from Chapter 4 of WHO guidelines which was implemented by Zanjan Water Company were utilized (Table 1).

3. Results

Findings of the present study regarding the safety level of the water supply system of the Tahm dam with the implementation of WSP phases are shown in Table 2. In this study, four main components of the water supply system were examined (Table 3). Coordinated implementation of WSP in four components of the Zanjan water supply system from the Tahm dam during 2019 is indicated in Fig. 2. The results of the related percentages of WSP implementation in four major components of the water supply system are shown in Fig. 3a–d. In Table 4, the results of identifying the most important risks and assessing the risk of the water supply system and the proposed corrective actions according to the experts' views are reported.

4. Discussion

In this study, 325 out of 440 points of full implementation score of the WSP were obtained. This represented 73.86% of WSP-compliant implementation of the drinking water supply and distribution system in Zanjan City from the Tahm dam. In similar studies executed on different water systems of Iran, the implementation of WSP total score has ranged from 21% to 68%: Hoshyari et al. [16] in Hamadan City showed 50%; Aghaei et al. [14] in Ardebil City 21.14%; Eslami et al. [6] in Zanjan reported 52.95%; Eslami et al. [5] in Birjand 43.18%; Shafiei et al. [18] in Qom Desert 48.86%; and Shafiei et al. [17] in Qom City 68.64%. In the present study, the team formation, system description, and verification phases had the highest program score (100%) and the program related to the improvement and promotion phases gained the lowest execution score (45.83%). In Shafiei et al. [17] study, neither the improvement nor the promotion programs received the lowest scores.

The risk identification stage is introduced as a key parameter in the WSP implementation progress in research, as reported in Japan [19]. This stage showed in the studies of Hamadan cities 86%, Birjand 52%, 100% in Qom, and 32% in Ardabil compliance implementation with WSP [5,14,16,17]. Risk identification stage, in the present study, according to Table 3, was 79 out of 100 possible points and showed 79% compliance with WSP implementation.

The program result outputs regarding the main components of WSP implementation progress of Zanjan water supply system from Tahm dam demonstrated that water treatment had the highest progress, whereas catchments, distribution networks, and consumption points had less progress in the implementation. It has been reported in previous studies that the treatment step has the highest [6,14,16], while the consumption point has the lowest percentage of compliance with the WSP.

Risk assessment results showed that Sewage and waste discharges to water sources or catchment by villagers and local communities, low consumer awareness, old pipes, and aging water infrastructure, and deficiency in inverting washing system of filter, respectively, were the most important risks identified in this study were the highest risk assessment points in each component of the Zanjan drinking water system. According to the comparison of the results of this study with those of other works including Wise [20] in Melbourne and Staben et al. [21] in Germany, it is estimated that water source protection is the first and most important obstacle for preventing contaminants from entering the water quality system and reducing its quality. The next important steps are to identify, control, and mitigate the risks involved in the treatment phase and the distribution process.

Similar to our studies, Kanyesigye et al. [22], in the study of 20 cities in Uganda in 2019, ranked sewage entry into drinking water resources as the highest risk. Also, Aghaei et al. [14] and Hoshyari et al. [16] have defined the depletion of pollutants in the catchment and the existence of worn-out infrastructure as a risk factor for assessing the risk of their studies. Gunnarsdottir et al. [23] showed that using appropriate methods in implementing the water safety program can help quickly identify the risk factors and pathogens in water resources, especially in the old construction sources, and improve the water quality from the catchment to the consumption point.

One of the main causes of the malfunction of the sand filter in the treatment is filter bed discharge in Zanjan. According to studies, the accumulation and deposition of particles in the filter bed resulting in a drop in the filter bed, which is required during filter washing [24]. Hydraulic parameters such as the height of bed expansion, water discharge, desired expansion, and bed pressure drop should be considered to perform an optimum sand washing inversion operation [25]. Water purification should be done to prevent microbial growth, pipe corrosion, and sediment formation. Good quality water in the distribution network depends on the proper design and operation of the system [26]. Contaminated water enters the distribution network when water pipes break and leakage of pipes results in the malfunction of the system and worn-out infrastructure.

Consumers are responsible for maintaining safe water delivered, preventing contamination during storage and

Table 1
Semi-quantitative risk assessment matrix

High risk ≥ 20 Medium risk 10–19 Low risk < 10				Severity				
				Wholesome water	Short term or localized, not health-related non-compliance or esthetic	Widespread esthetic issues or long term non-compliance not heath related	Potential long term health effects	Potential illness
				Insignificant	Minor	Moderate	Major	Catastrophic
				1	2	3	4	5
Likelihood	Has not happened in the past and it is highly improbable that it will happen in the future	Most unlikely	1	1	2	3	4	5
	Is possible and cannot be ruled out completely	Unlikely	2	2	4	6	8	10
	Is possible and under certain circumstances could happen	Moderate	3	3	6	9	12	15
	Has occurred in the past and has the potential to happen again	Very likely	4	4	8	12	16	20
	Has occurred in the past and could happen again	Almost certain	5	5	10	15	20	25

Risk = Likelihood × Severity

Table 2
Implementation of water safety plan (WSP) implementation of Zanjan water supply system safety status from Tahm dam

Overall progress with WSPs (Tables 3–12)			Zanjan
			July-2019
Step	No. of questions	Total possible points	Score (% Implemented)
WSP team	5	20	20 (100.00%)
System description	2	8	8 (100.00%)
Hazard identification and risk assessment	7	100	79 (79.00%)
Control measures and validation	5	68	39 (57.35%)
Improvement plan	3	48	22 (45.83%)
Operational monitoring	4	64	43 (67.19%)
Verification	8	32	32 (100.00%)
Management procedures	3	36	30 (83.33%)
Supporting programs	2	8	4 (50.00%)
Review of the WSP	5	56	48 (85.71%)
Total	44	440	325 (73.86%)

Table 3
Compliance implementation of fourth component of Zanjan City water supply system from Taham dam with water safety plan

System components			Zanjan
			July-2019
	No. of questions	Total possible points	Score (% Implemented)
Catchment	23	88	59 (67.00%)
Treatment	23	88	74 (84.00%)
Distribution	23	88	58 (66.00%)
Point of use	23	88	54 (61.00%)
Total	92	352	245 (69.6%)

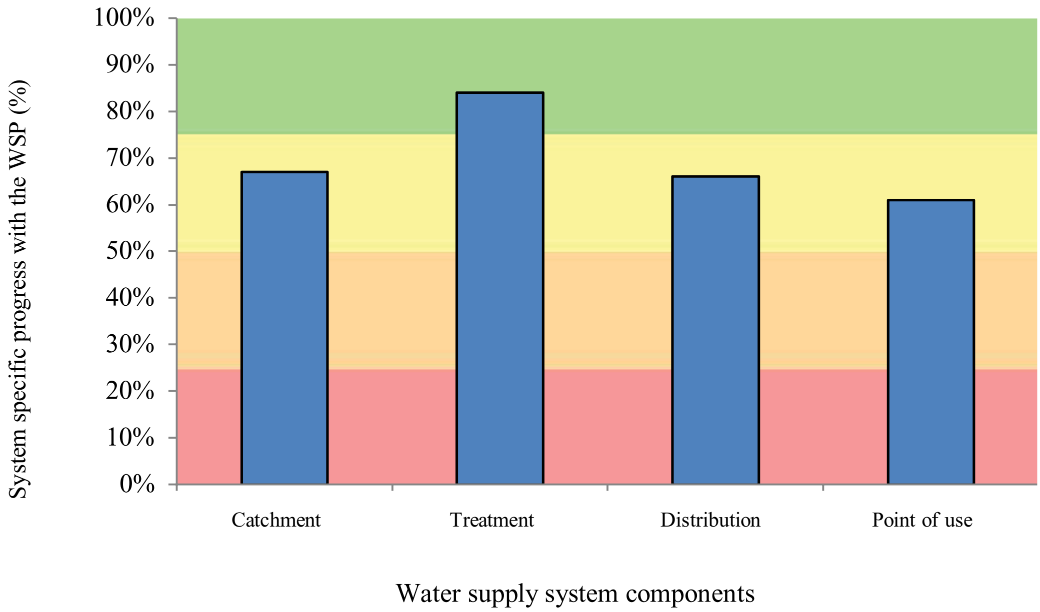

Fig. 2. Overall water supply system components progress of Zanjan City from the Tahm dam in 2019 in compliance with WSP.

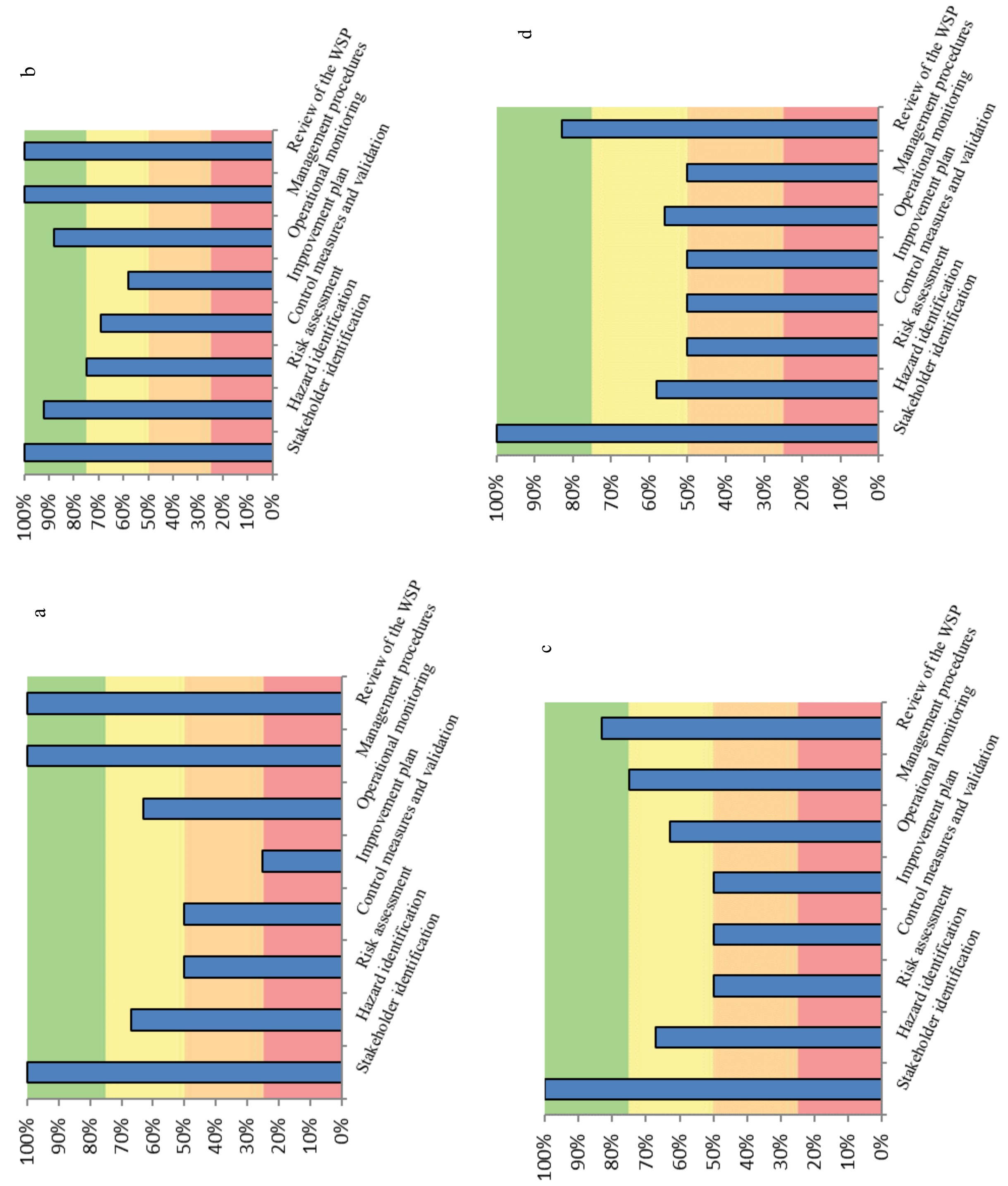

Fig. 3. Distinctive progress of the water supply system components of Zanjan City from the Tahm dam in 2019 in compliance with WSP. Catchment (a), treatment (b), distribution network (c), and (d) consumption point.

Table 4
Prioritization and risk assessment of most important hazardous event in Zanjan water supply system

System component	Hazardous event (source of hazard)	Hazard type	Risk assessment			Corrective action
			Likelihood	Severity	Risk	
Catchment	Sewage and waste discharges to water sources or catchment by villagers and local communities	Chemical/ physical microbial	5	5	25	• Wastewater collection and treatment systems in some rural areas around the river and surface waters • Preventing dumping of waste in upstream via the development of a waste management system Promoting awareness in the community living in that area who can affect water quality • Promoting awareness in the community living in that area who can affect water quality
Catchment	Thermal stratification of raw water source in the catchment area	Chemical/ physical	3	4	12	Mixing and aerating the bottom layers of the source, disrupting the thermal classification of water
Treatment	Problems with poor filter performance	Chemical/ physical microbial	3	3	9	Regulate the filter backwashing cycle and its reuse (troubleshooting possible) • Online monitoring of turbidity and reducing filtration rate by decreasing the current input in high turbidity times
Treatment	Deficiency in invert washing system of filters	Chemical/ physical microbial	3	4	12	• Proper operation of pretreatment processes, coagulation, and flocculation • Select the optimal bed expansion between 25% and 30% for smooth wash • Choosing the right coagulant or polymer additive for washing water • Adjustable temperature for leakage • Considering the proper duration and intensity for inverse filter washing
Distribution	Contaminated water enters the distribution network during blasting, breakage, leakage, or repair of water lines (especially at low pressures)	Chemical/ physical microbial	3	3	9	• Identification and fixing of defects in points of distribution system where frequent leaks, explosions, or defects are reported • Using leak detectors to better manage the water supply network • Active control (monitoring program for continuous and regular leakage in the distribution network) • Proper pressure control in the grid • Immediate use of materials in the repair of water pipelines
Distribution	Old pipes and aging water infrastructure	Chemical/ physical microbial	5	3	15	• Investment on replacing and renewing of old Infrastructure and pipes in the distribution system • Continuous inspection
Point of use	Low consumer awareness	Chemical/ physical	4	4	16	• Consumer culture • Timely and honest information to consumers • Changing the lifestyle of people using drinking water, especially in children and adolescents, through educational centers • Legal and control measures
Point of use	Internal leakage of building pipes	Chemical/ physical microbial	3	3	9	• Plumbing repairs to the interior of the building by a specialist • Using high-quality pipes and materials

Risk = Likelihood × Severity

transportation, preventing water pollution activities, and providing feedback on the quality of water services [27]. It is therefore important to promote public awareness, especially through education in women's groups in the community, about water safety and the principles of WSPs, particularly in areas with intermittent water supply systems where water storage is carried out at home. Consumer satisfaction is one of the pillars of WSP effectiveness and consumer feedback can be an important source of information on effective water system performance [1,13,28].

5. Conclusion

The results of the risk assessment showed that the rural sewage to catchment areas had the highest and existing points of the distribution network and geological issues had the lowest risk in the water supply system of Zanjan City. It was also found that Zanjan's water system safety was at a moderate level in terms of compliance with WSP (73.86%). It seems that, if WSP could be correctly implemented by the water supplier and more emphasize is made on the improvement plan stage which achieved the lowest score in the application of WSP in this study, we can expect more positive results in terms of enhancing the quality and safety of drinking water.

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