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The Risk Assessment of the Critical Points in the Water Safety Plan Based on the Characterization and Validity of Microbial Indicator Control: A Case Study in Qom Province, Iran

Hassan Izanloo [a] | **Zahra Atafar** [b] | **Yadollah Ghafuri** [a*]

a. Research Center for Environmental Pollutants, Qom University of Medical Sciences, Qom, Iran.
b. Social Development and Health Promotion Research Center, Health Institute, Kermanshah University of Medical Sciences, Kermanshah, Iran.

***Corresponding author:** Research Center for Environmental Pollutants, Qom University of Medical Sciences, Qom, Iran. Postal code: 77789876.
E-mail address: yadollahghafuri@yahoo.com

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ABSTRACT

Background: The water safety plan is the new approach of the WHO to ensuring the quality and safety of drinking water. This study aimed to investigate the microbiological quality control accreditation process in the identification and risk assessment of the critical points in the water safety plan of Qom province, Iran.
Methods: This descriptive study was conducted in two phases; initially, the microbial indicators of microbial validation were monitored (fecal streptococci, heterotrophic plate count, Escherichia coli, and bacterial ratio). The other qualitative and chemical parameters of water in the distribution network were also assessed (pH, residual chlorine, temperature, and turbidity). The DotMapper software was used to identify the critical control points. The second phase involved risk assessment and critical control point design.
Results: We selected 160 urban water distribution network points. In 30 points, the critical points were determined based on the fecal contamination indicators using the DotMapper software. Based on the risk assessment model and semi-quantitative method, the urban water distribution network was considered high-risk.
Conclusion: Considering the implementation steps of the water safety program in urban water distribution networks, attention must be paid to validating microbial indicators and the impact on identifying critical control points and control criteria.

1. Introduction

The water supply industry is vitally important not only to maintain community health, but also for the sustainability of industries, businesses, and agriculture. Inadequate water supplies hinder the progress of communities and human life [1]. The World Health Organization (WHO) has proposed an approach to achieving the goals of implementing the drinking water safety program (WSP) [2], which is primarily based on risk management that addresses the prevention of drinking water source pollution, water purification to reduce/eliminate contamination to meet the standards, and prevention of water pollution during storage, distribution, and consumption [3, 4]. In fact, the WSP approach has been developed as a water safety plan based on the comprehensive assessment of the hazards affecting the quality of the water distributed to consumers [5].

The present study aimed to assess the impact of the microbiological quality control and validation process on the identification and assessment of the risk of critical points in the water safety program in Qom, Iran. To this end, we evaluated the implementation of the drinking water safety program based on the recommendations and models of the WHO and the Ministry of Health, particularly the

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implementation steps involving the identification of risks and hazards, risk assessment, identification and validation of the control measures in the WSP, and the supply, transfer, and distribution of drinking water networks.

Furthermore, the safety of the water distribution system network in Qom was examined through the identification and risk assessment of the critical points in the WSP and assessing the validity of the microbial water quality indicators [6].

2. Materials and Methods

2.1. Design of Microbial Monitoring

2.1.1. Sampling Site

Qom is the capital of Qom province, which is located at the border of the central desert of Iran (Kavir-e Markazi) and geographical coordination of 34°38′24″N 50°52′35″E. In the 2017 census, the population of this province was estimated at 1,174,036 (595,704 men, 578,332 women). Considering the development of Qom city and its population growth, the issue of water supply in this area has attracted attention. Accordingly, two drinking water distribution networks (urban pipeline networks and purified water distribution networks) have been treated using the reverse osmosis system (RO). This cross-sectional study was conducted at 160 points of an urban water distribution network. The sampling plan was repeated twice per season, and sampling time was the fall of 2019 location of studied area and sampling point is mentioned in the figure 1 and 2 [6].

2.2. Water Quality Indicator Tests

In this research, the criteria for the monitoring of the quality of the microbial indicators and validity process in the water distribution network were considered. The microbial indicators of microbial validation included fecal streptococci (FS), heterotrophic plate count (HPC), Escherichia coli (EC), and FS/FC ratio, which were assessed based on national standard tests. In addition, the qualitative and chemical parameters of water in the distribution network included pH, residual chlorine, temperature, and turbidity, which were evaluated using the standard methods for the examination of water and wastewater [7-9].

2.3. Design of the Risk Assessment and Critical Control Point

The critical points were the samples of the points with positive results for the second time after the corrective interventions based on the microbial indicators. The identified critical points were mapped using the DotMapper software based on their location in the urban water distribution network. DotMapper is an open-source tool used for the development of interactive point maps based on the statistical software R. These point maps display the locations of cases and could be color-coded to convey data on categorical variables [9]. In the next phase of the study, the events and risks of the critical points were assessed. For the risk assessment process, a semi-quantitative matrix method was used. In this method, the risk level was obtained by the multiplication of the severity and likelihood criteria (Table 1). The likelihood categories and severity criteria that were used in the risk assessment are presented

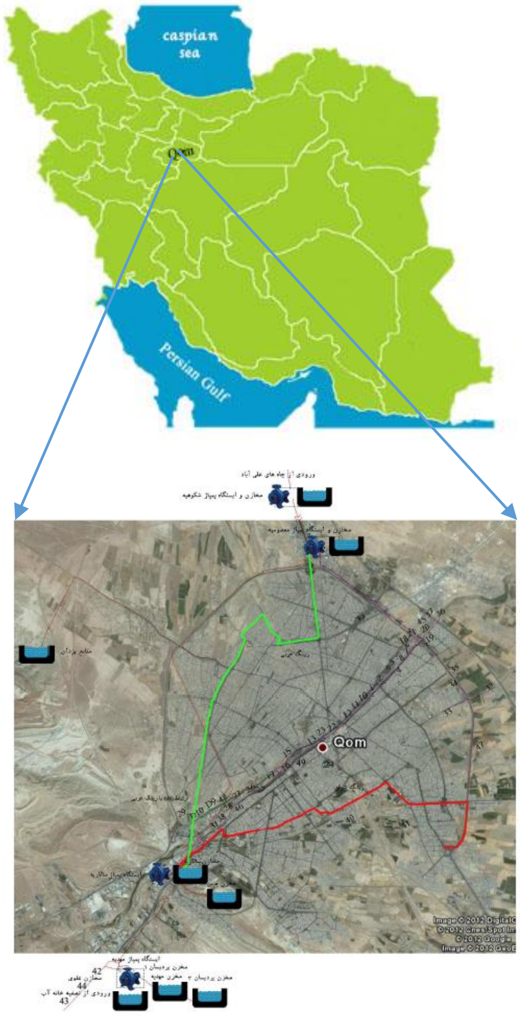

Figure 1: Location of Studied Area and Sampling Points

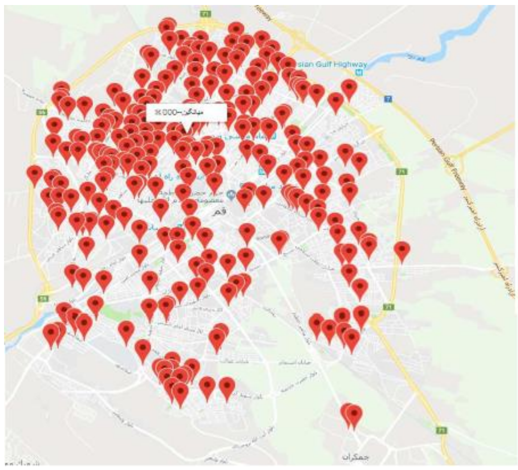

Figure 2: Sampling sites based on Location in Qom Water Distribution Network

in Table 2 location of studied area and sampling point is mentioned in the Figure 1 and 2 [10,11]. In order to perform the risk assessment,interviews were conducted with experienced personnel of health centers and water and wastewater engineering companies that were properly oriented on the risk assessment and management practices of the WSP.

Table1: Semi-quantitative Risk Matrix

	Risk Matrix	Severity				
		Insignificant Score: 1	**Minor Score: 2**	**Moderate Score: 4**	**Major Score: 8**	**Catastrophic Score: 16**
Likelihood	Almost certain Score: 5	5	10	20	40	80
	Likely Score: 4	4	8	16	32	64
	Foreseeable Score: 3	3	6	12	24	48
	Unlikely Score: 2	2	4	8	16	32
	Most unlikely Score: 1	1	2	4	8	16

*Black color in the matrix risk table have high risk ranking

Table 2: Likelihood Categories and Severity Criteria

Item	Definition
Likelihood Categories	
Almost certain	Once per day
Likely	Once per week
Foreseeable	Once per month
Unlikely	Once per year
Most unlikely	Once every 5 year
Severity Criteria	
No effect	Has no effect on health
Minor	Minor injury
Major	Injury
Hazardous	Serious or fatal injury
Catastrophic	Death

3. Results and Discussion

At 30 points (18.7%) of the urban water distribution network, the critical contamination points were identified based on each microbial indicator or mismatch with the other qualitative and chemical parameters. Figure 3 shows the distribution of the critical control points (red points) in part of the water distribution network in Qom using the DotMapper software. The green dots are the points that meet all the standards of the drinking water quality in the sampling and monitoring processes. Figures 3 and 4 depict the results of the regression model to determine the correlations of HPC with turbidity and total load factors in the urban water distribution network.

Table 3 shows the risk assessment of the identified critical control points based on the validation of the microbial indictors.

The microbial status of the urban distribution network was also evaluated based on the validation parameters.

Although the percentage of microbial contamination according to EC (E.coli) indicator was zero in all samples, in 6% of samples of fecal streptococcal and in 3% of samples, heterotrophic plate counts (HPC) > 500 were determined with an average of 55.2. The mean values of turbidity, pH, and residual chlorine in the urban distribution network were estimated at 1 ± 0.4 NTU, 8.57, and 0.4 ± 0.2 mg/l, respectively.

In the present study, the identification of 30 critical points in the urban water distribution network was performed after the evaluation of the control measures. Based on the regression model, HPC was negatively correlated with turbidity and residual chlorine (Cl_2). Since HPC is typically low in high turbidities, the behavior of heterotrophic water populations is rather complex and dependent on other variables. As is shown in Figure 4 regarding the correlation between residual chlorine and HPC in the drinking water distribution network, the effect of high residual chlorine (Cl_2) on the reduction of microbial population was evident. On the other hand, Figures 3 and 4 shows the analysis of the correlations between the microbial populations and variables such as turbidity and residual chlorine, which should be assessed separately.

According to the results of the semi-quantitative risk assessment (Table 3) and considering the microbial validation and other water quality parameters, it could be stated that the water distribution network in Qom is classified as high-risk. This is consistent with the results of the previous studies in this regard. In the study by Hoshyari et al. (2019) regarding the risk assessment of water supply system safety based on the WSP implementation in Hamadan (Iran), the findings indicated that out of the total

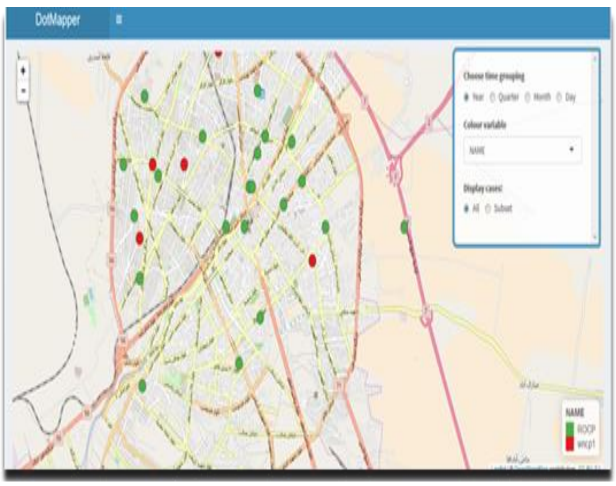

Figure 3: Distribution of Critical Control Points (red points) in Part of Water Distribution Network in Qom Using DotMapper Software

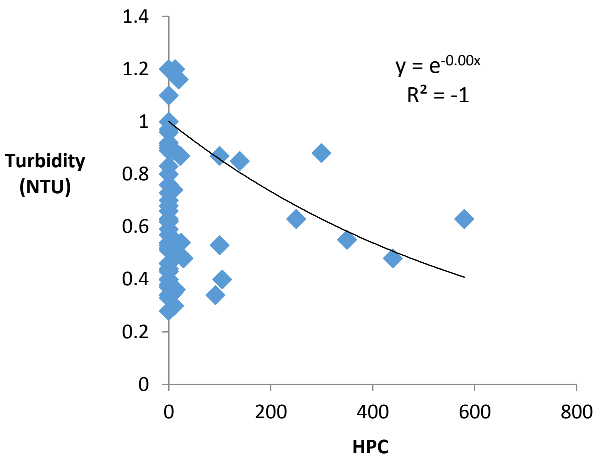

Figure 4: Correlation between Turbidity and Heterotrophic Plate Count in Drinking Water Distribution Network

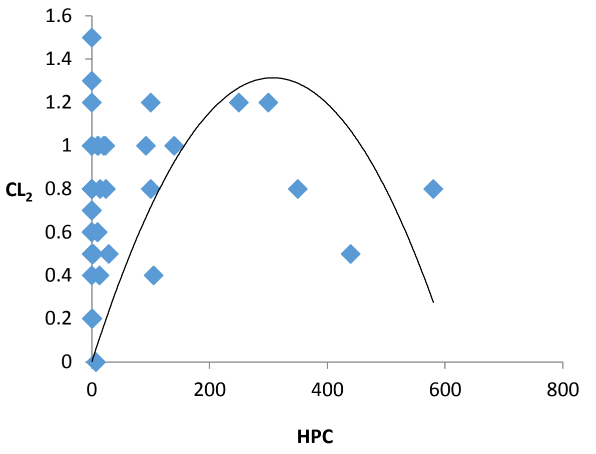

Figure 5: Correlation between Residual Chlorine and Heterotrophic Plate Count in Drinking Water Distribution Network

score of 440 (complete implementations of WSP) and based on the score of 384 (investigation of various study phases), score 220 was achieved with 50 % coordination with the WSP. In the mentioned study, the risk assessment results indicated that the most important hazards in the water supply system of Hamedan (Iran) were the discharge of wastewater from a village and agriculture in the catchment, blocked filter and algae in treatment, old pipes, excavation, and installation facilities in distribution, pressure drop and construction of water wells at home in the point of use [10].

In this regard, Fahiminia *et al.* (2018) conducted a system assessment and analyzed the hazards in the WSP in a desert city in Iran. The results of the system analysis indicated the general score of 48.18%, as well as recognized risks in the distribution network. Furthermore, the mentioned study indicated that to increase the score, the WSP should be fully performed, and a program should be developed to control the recognized risks. Accordingly, the results of the present study are consistent with the study by Fahiminia *et al.* (2018) [12].

Tsoukalas and Tsitsifli conducted a critical evaluation of WSPs and HACCP implementation in water utilities. According to the obtained results, the implementation of the hazard assessment of critical control points and WSPs in drinking water systems had major benefits in improving the quality of drinking water, which is in line with the results of the present study [11].

In another study, Park et al. assessed the microbiological water quality of six water source categories in northeastern Uganda, reporting that sanitary surveys and routine monitoring based on defined standards (e.g., WHO), the drinking water standard of zero thermotolerant coliforms per 100 milliliters cannot predict water quality accurately. This is in line with the results of the present study [13].

The comparative analysis of the current microbial water quality risk assessment and management practices in British Columbia and Ontario (Canada) by Gemma Dunn *et al.* (2014) demonstrated considerable variability in microbial risk assessment frameworks and management tools, so that the approaches would vary between provinces, within provinces, and between similar agencies. Furthermore, the comprehensive risk assessment and management plans to identify and prioritize potential threats to water quality at each step in a water supply chain of a specific system (from source to tap) to mitigate threats to drinking water by the WSP as a risk assessment tool have been implemented by Ashbolt (2004), Davison *et al.* (2005), Byleveld *et al.* (2008), Hamilton *et al.* (2006), Schijven *et al.* (2011), Smeets *et al.* (2010), Summerill *et al.* (2010a, 2010b), Vieria (2007), Yokoi *et al.* (2006), Jayarante (2008), Miller *et al.* (2005), Gelting (2009), Austin *et al.* (2012), Hrudey (2011), and Bartram *et al.* (2009) [14]. The findings of the other studies in this regard have emphasized that the WSP cannot be guaranteed only by applying certain control parameters to the water distribution network, such as *E. coli* fecal contamination index or the standard residual chlorine limit in the water distribution network [15-17].

Table 3: Risk Assessment Results of Critical Control Points

Code of events	Hazards	Hazardous events	Risk Assessment			
			Likelihood	Severity	Risk	Risk Ranking
Qom-Net-01	Physical, chemical	Lack of specifications and attributes of urban water distribution network	8	7	56	high
Qom-Net-02	Physical, chemical and microbial	Occurrence of chemical microbial contamination and increased turbidity due to fractures caused by increased water pressure in water distribution network	8	8	64	high
Qom-Net-03	Physical, and microbial	Incidence of microbial contamination and increase in turbidity and chemicals due to fractures and Exhaustion of distribution network	8	8	64	high
Qom-Net-04	Physical, and microbial	Increased turbidity and microbial load of water caused by accumulation of sediments at the blind and end points of the network	9	8	72	high
Qom-Net-05	Physical, chemical and microbial	Leakage and infiltration of physical and microbial contamination on distribution networks due to construction, repair and development operations	9	8	72	high
Qom-Net-06	Physical, chemical and microbial	Incidence of physical, chemical and microbial contamination from direct injection of wells into water distribution network	8	8	64	high
Qom-Net-07	Microbial and chemical	Direct injection into well (number 13) and possible increase of nitrate concentration into water distribution network	8	8	64	high

4. Conclusion

Considering the implementation steps and steps of the WSP in urban water distribution networks, special attention must be paid to the validation of microbial indicators and the impact on the identification of critical control points and control criteria.

Authors' Contributions

All the authors contributed to the preparation of the manuscript. Y.G.,H.I., and Z.A., designed the manuscript and contributed to data collection and data analysis.

Conflict of Interest

The Authors declare that there is no conflict of interest.

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