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The microbial and physicochemical quality of the storage tanks and distribution networks of drinking water in the villages of Saqqez in Kurdistan Province, Iran (2018)

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ABSTRACT

Lack of access to safe drinking water is an important health concern in developing countries. The present study aimed to investigate the microbial and physicochemical quality of the drinking water storage tanks and distribution networks in the villages of Saqqez in Kurdistan province, Iran in the summer of 2018. This descriptive, cross-sectional study was conducted by sample collection from the storage tanks and distribution networks in 20 villages covered by Saqqez Rural Water and Wastewater Company during three months. Chemical tests were performed based on titration, and physical tests were carried out using instrumental methods. The culture of the specimens was performed to determine the total and fecal coliforms using the most probable number (MPN method. Data were analyzed in SPSS and Excel software. In 100% of the storage tank samples, total and thermophilic coliforms were within the national and international standards. In the distribution networks, 11.67 and 33.3% of the samples had higher total and thermophilic coliforms than these standards, respectively. The residual chlorine parameter was higher than the national standards in 15% of the storage tank samples and 25.03% of the distribution network samples. Turbidity, total hardness, chloride, electrical conductivity, pH, and TDS in the storage tanks and distribution networks were in accordance with the national and international standards. All the physical and chemical parameters (except for chlorine residues) were within the national and international standards, and the maximum total and fecal coliforms were 6 MPN, which could be maintained in the standard range via chlorination.

Keywords: Total coliform, Fecal coliform, Drinking water, Storage tanks, Distribution networks

Introduction

Undeniably, pure and clean water is one of a basic need of civilized humans,[1] and water constitutes 65% of the body weight. The availability of safe drinking water is an important health concern in most countries across the world.[2] Water plays a pivotal role in regulating the transportation of nutrients, elimination of toxins, heat regulation, digestion, and activities of various organs in the body. However, the consumption of contaminated water leads to numerous diseases.[3] Approximately 80% of the Earth's surface is covered by water, 97% of which is confined to the oceans and seas, and 2.4% is concentrated in glaciers and ice. As such, less than 1% of water resources are accessible for drinking, agricultural activities, and domestic and industrial use.[4] According to the US Environmental Protection Agency (USEPA), more than 500 pathogens may be present in drinking water, and water treatment through the removal of pathogens by filtration or disinfection is considered an optimal approach to minimizing the number of

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pathogens in drinking water.[5]

Waterborne diseases are mainly caused by intestinal pathogens.[6] According to the World Health Organization (WHO), out of 4 billion diarrhea cases, 2.2 million patients die each year due to the lack of access to safe drinking water.[7] Drinking water must not have an unpleasant odor and taste, and it must be free of pathogens as well. According to the WHO estimates, 80% of the diseases in the world (e.g., diarrhea, jaundice, and typhoid) are caused by the consumption of contaminated water.[8]

In rural areas, the continuous monitoring of water quality is essential due to factors such as the scattering of villages, old facilities and water distribution networks, poor hygiene, and dispersal of animal waste.[9] Total coliforms and fecal coliforms are index organisms that are most commonly used to determine the microbial quality of drinking water.[10] The most important factor in determining the purity of water is the microbial factor, while physical and chemical factors are of secondary importance in this regard.[11]

Today, water scarcity is a health threat to humans, animals, and plant life in many countries (including Iran) as an economic and agricultural bottleneck. Moreover, factors such as population growth, extravagant consumption, and industrialization have given rise to numerous environmental issues, and water pollution is considered to be a major consequence in this regard.[12] In a study conducted by Fazli *et al.*, the microbial status of drinking water was investigated in Ijroud urban and rural distribution systems in Zanjan province, Iran.[13]

Given the importance of controlling and adapting various drinking water parameters to ensure consumer health, the present study aimed to investigate the microbial status and physicochemical parameters of the drinking water storage tanks and distribution networks in the villages of Saqqez, Iran and compare the results with the national and international standards.

Materials and methods

Study area

This descriptive, cross-sectional study was conducted in the villages covered by Saqqez Rural Water and Wastewater Company during 2018-6-22-2018-8-26. Saqqez is one of the northern cities in Kurdistan province, which is composed of four main districts, including the central, Imam, Sarshiv, and Ziviyeh districts. Saqqez city has 308 villages, only 164 of which are under the supervision of the Rural Water and Wastewater Company.

Sampling method

Sampling was carried out from the water storage tanks and distribution networks (beginning, middle, and end of the networks) in 20 villages covered by Saqqez Rural Water and Wastewater Company in all the mentioned districts. In total, 80 samples were collected for microbial tests, and 80 samples were obtained for chemical tests (60 samples from the distribution networks and 20 samples from the storage tanks).

Multistage sampling was used for sample collection to assess the microbial status and physical and chemical parameters of water, and the criteria for the selection of the villages in each district was distance from the city center (two villages with distance of 15 km from the city center, two villages with the distance of 15-30 km, and one village with the distance of more than 30 km) and the type of the supply resources in each district (two villages had water wells, two villages had springs, and one village had both springs and water wells). Microbial sampling was performed in wide-mouth glass borosilicate containers, and 10% sodium thiosulfate was added to neutralize residual chlorine prior to sterilization.

The chemical samples were collected in three-liter plastic containers, and the secondary contamination of the microbial samples was prevented during sampling, transfer, and performing the tests. The samples were transferred in cool boxes and ice bags without contact with the sampling container.

Experimental procedures

Physical tests were performed using an instrumental method with the measurement of turbidity (Wagtech Turbidity Meter, UK), electrical conductivity (Metrohm Conductivity Meter, Switzerland), pH (Wagtech pH meter, UK), and total dissolved solids (TDS; TDS meter, HM Digital, Iran).[14] Chemical tests were also performed using the titrimetric method, including total hardness and chloride. Total hardness was measured via EDTA titration, and chloride was determined via potassium chromate titration.[15]

The microbial tests included the measurement of total coliforms and fecal coliforms, which were performed using the most probable number (MPN) method in nine tubes. The weak and strong lactose broth medium was used in the probability stage, brilliant green bile broth medium was utilized in the confirmed test stage and for total coliforms, and the EC broth medium was employed in the confirmatory stage and for the determination of fecal coliforms.[16] All the experimental materials used in the study were prepared by Merck, Germany.

Data analysis was performed in SPSS version 20 using one-sample t-test, Pearson's correlation-coefficient, and mean and standard deviation. In addition, the obtained results were compared with the national and international standards (USEPA and WHO).

Results and discussion

Table 1 shows the mean parameters in the studied water storage tanks and distribution networks. Accordingly, in the water samples obtained from the storage tanks, the residual chlorine (0.6005), pH (7.350), TDS (314.70), electrical conductivity (EC) (595.7250), and total hardness (234.300) had higher mean values, while turbidity (0.6252), total coliforms (0.483), and thermophilic coliforms (0.10) had higher mean values in the distribution network. However, the total hardness in the storage tanks and distribution networks had identical means (75.826), and the total and fecal coliform tests were negative in all the storage tanks of the studied villages.

Table 1. Descriptive statistics of water storage tanks, distribution networks, and city districts

Parameters	Descriptive statistics	Storage tank					Distribution network system				
		Imam district	Ziviyeh district	Central district	Sarshive disrict	All of tanks	Imam district	Ziviyeh district	Central district	Sarshive disrict	All of networks
Residual chlorine (mg/L)	Mean ± STD	0.66 ± 0.2	0.58 ± 0.22	0.56 ± 0.33	0.59 ± 0.11	0.6 ± 0.21	0.66 ± 0.18	0.52 ± 0.25	0.49 ± 0.34	0.49 ± 0.24	0.53 ± 0.26
Turbidity (NTU)	Mean ± STD	0.58 ± 0.15	0.64 ± 0.17	0.58 ± 0.23	0.64 ± 0.15	0.61 ± 0.16	0.58 ± 0.15	0.58 ± 0.14	0.64 ± 0.16	0.70 ± 0.19	0.62 ± 0.18
pH	Mean ± STD	7.16 ± 0.21	7.28 ± 0.34	7.48 ± 0.28	7.3 ± 0.3	7.35 ± 0.28	7.16 ± 0.19	7.3 ± 0.3	7.51 ± 0.31	7.37 ± 0.26	7.22 ± 0.29
TDS (mg/L)	Mean ± STD	319.4 ± 54.54	296.8 ± 42.1	301.2 ± 34.82	241.4 ± 46.21	314.7 ± 45.05	319.4 ± 50.5	296.5 ± 39.04	300.13 ± 33.27	339.8 ± 41.89	31.35 ± 14.14
Electrical conductivity (μs/cm)	Mean ± STD	663.26 ± 60.5	521.3 ± 94.49	585.7 ± 60.35	612.56 ± 84.09	595.72 ± 87.53	663.2 ± 56.01	520.1 ± 87.75	585.63 ± 36.64	609.82 ± 76.63	594.44 ± 86.12
Chloride (mg/L)	Mean ± STD	86.83 ± 27.95	73.97 ± 9.59	70.75 ± 23.18	71.75 ±16.3	75.82 ± 19.92	86.83 ± 25.88	73.97 ± 8.88	70.75 ± 21.46	71.75 ± 15.11	75.82 ± 19.58
Total hardness (mg/L $CaCO_3$)	Mean ± STD	238.8 ± 32.97	236 ± 31.24	238.8 ± 48.22	233.2 ± 57.37	234.3 ± 40.38	228.8 ± 30.53	236 ± 28.92	238.8 ± 44.64	233.47 ± 52.91	266.23 ± 39.62
Total coliform (MPN)	Mean ± STD	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.40 ± 0.06	0.60 ± =.05	0.93 ± 0.08	0.48 ± 0.03
Thermophilic coliform (MPN)	Mean ± STD	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.20 ± 0.07	0.20 ± 0.07	0.1 ± 0.05

Table 1 also shows the mean of each studied parameter in the water storage tanks and distribution networks in terms of districts. In the samples obtained from the storage tanks, the residual chlorine in Imam district (0.66), turbidity in Ziviyeh and Sarshiv districts (0.64), pH in the central district (7.48), TDS in Sarshiv district (341.40), electrical conductivity in Imam district (663.26), chloride in Imam district (86.83), and total hardness in Sarshiv district (333.20) had the highest mean values. In the samples of the distribution networks, the residual chlorine in Imam district (0.66), turbidity in Sarshiv district (0.70), pH in the central district (7.51), TDS in Sarshiv district (339.80), electrical conductivity in Imam district (663.26), chloride in Imam district (83.83), total hardness in the central district (238.80), total coliforms in Sarshiv district (0.93), and fecal coliforms in the central and Sarshiv districts (0.20) had higher mean values comparatively.

According to the information in Table 2, the highest mean residual free chlorine (0.60 mg/L) was observed at the beginning of the distribution networks, while turbidity had the highest mean value (0.68) at the end of the distribution networks. In addition, pH had the highest mean value (7.32) at the end of the distribution networks, and TDS had the highest mean value (314.70) at the beginning of the distribution networks. Electrical conductivity had the highest mean value (595.73) at the beginning of the distribution networks, and the highest mean value of residual chlorine was observed at the beginning of the networks (75.83). On the other hand, total hardness (22.20) had an equal mean value at the beginning, middle, and end of the distribution networks. The total coliforms (1.10) and fecal coliforms (0.30) had the highest mean values at the end of the networks.

Table 2. Descriptive statistics of distribution networks based on beginning, middle, and end of distribution networks

		Beginning	Middle	End
Free residual chlorine	Mean ± STD	0.60 ± 0.21	0.56 ± 0.26	0.46 ± 0.30
Turbidity	Mean ± STD	0.61 ± 0.17	0.62 ± 0.18	0.68 ± 0.20
pH	Mean ± STD	7.31 ± 0.29	7.32 ± 0.28	7.37 ± 0.32
TDS	Mean ± STD	314.7 ± 45.06	314.3 ± 44.55	312.87 ± 45.12
Electrical conductivity	Mean ± STD	595.73 ± 87.53	594.9 ± 87.53	592.71 ± 87.53
Chloride	Mean ± STD	75.83 ± 19.92	75.83 ±19.92	75.83 ± 19.92
Total hardness	Mean ± STD	234.2 ± 40.29	234.2 ± 40.28	234.2 ±40.28
Total coliform	Mean ± STD	0.00 ± 0.00	0.35 ± 0.09	1.1 ± 0.07
Fecal coliform	Mean ± STD	0.00 ± 0.00	0.00 ± 0.00	0.30 ± 0.09

According to the results of the present study, the minimum and maximum values of the studied parameters in the samples obtained from the water storage tanks were as follows: residual chlorine (0.18-0.88 mg/L), turbidity (0.32-0.85 NTU), pH (6.9-7.8), TDS (226-415), electrical conductivity (453.5-750 µs/cm), chloride (42.88-107.2 mg/L), and total hardness (184-328 mg/L). It is also notable that the total and fecal coliform tests were negative in the samples obtained from the storage tanks. The minimum and maximum values of the mentioned parameters in the samples obtained from the water distribution networks were as follows: residual chlorine (0.18-088 mg/L), turbidity (0.32-1 NTU), pH (6.9-8.2), TDS (226-410), electrical conductivity (470.2-750.7 µs/cm), chloride (42.88-107.2 mg/L), total hardness (184-327 mg/L), total coliforms (0-6 MPN per 100 mL), and thermophilic coliforms (0-3 MPN per 100 mL).

Table 3 shows the compliance rate of the studied parameters with the national and international standards. In 100% of the samples, the turbidity, electrical conductivity, total hardness, residual chlorine, pH, and TDS in the storage tanks were within the national and international standards. In 15% of the samples obtained from the storage tanks and 25.03% of the samples collected from the distribution networks, residual chlorine was not within the standard limits. On the other hand, the total and fecal coliforms in all the samples of the storage tanks were within the range of the national and international standards, while in the distribution networks, total coliforms and fecal coliforms were observed in 11.67 and 3.33% of the samples, respectively.

Table 3. Compliance rate of examined parameters with national and international standards

Points	Standard	Percentage	Chlorine	Turbidity	pH	TDS	EC	Chloride	Total hardness	Total coliform	Fecal coliform
Storage tank	Iran	Maximum desirable	85	100	100	100	100	100	35	100	100
		Maximum allowed		-	-	-	-	-	65	-	-
		Out of standard range	15	-	-	-	-	-	-	-	-
	WHO	Maximum desirable	-	25	100	100	-	100	30	100	100
		Maximum allowed	-	75	-	-	-	-	70	-	-
		Out of standard range	-	-	-	-	-	-	-	-	-
	EPA	Maximum desirable	-	100	100	100	-	100	-	100	100
		Maximum allowed	-	-	-	-	-	-	-	-	-
		Out of standard range	-	-	-	-	-	-	-	-	-
Distribution network	Iran	Maximum desirable	74.97	100	100	100	100	100	55	88.33	96.66
		Maximum allowed	-	-	-	-	-	-	45	-	-
		Out of standard range	2.03	-	-	-	-	-	-	11.67	3.33
	WHO	Maximum desirable	-	36.66	100	100	-	100	35	88.33	96.66
		Maximum allowed	-	63.33	-	-	-	-	65	-	-
		Out of standard range	-	-	-	-	-	-	-	11.67	3.33
	EPA	Maximum desirable	-	100	100	100	-	100	-	88.33	96.66
		Maximum allowed	-	-	-	-	-		-	-	-
		Out of standard range	-	-	-	-	-	-	-	11.67	3.33

Table 4 shows the inferential statistics of the studied parameters (one-sample t-test) and comparison of the measured values of each parameter with the optimal and permissible values based on the national and international standards. Accordingly, the turbidity of the water samples of the storage tanks was higher than the standard levels recommended by the WHO (T=2.901; P<0.05; significance: 0.009). Furthermore, total hardness was higher than the standard value reported by the Iranian guidelines and WHO limits (T=3.787; P>0.05; significance: 0.001). In the distribution networks, turbidity was higher than the recommended values by the WHO (T=5.745; P>0.05; significance: 0.000), while total hardness was higher than the optimal values proposed in the Iranian guidelines and WHO standards (T=6.698; P>0.05; significance: 0.00). Total coliforms were also higher than the recommended values in the Iranian guidelines, as well as the WHO and USEPA standards (T=1.426; P>0.05; significance: 0.159), and fecal coliforms were higher than the recommended values in the Iranian guidelines, as well as the WHO and USEPA standards (T=2.695; P>0.05; significance: 0.01). Other parameters studied were less than allowable and acceptable values announced by national standards, WHO and USEPA.

According to the findings of the current research, the mean value of the pH parameter in the storage tank was 7.3, which was within the confidence interval (6.5-8.5) and permissible levels (6.5-8.5) in the Iranian standards. Compared to the WHO standards, this parameter indicated the desired confidence interval (6.5-8.5) and was below the WHO permissible range (8-8.5). The mean pH parameter in the distribution networks was 7.3333, which is within the confidence interval (6.5-8.5) and acceptable values recommended by the Iranian standards (6.5-9.5). Compared to the WHO standards, the mean value of this parameter was within the optimal confidence interval (6.5-5.5), while it was less than the permissible range

(8.8.5) by the WHO. Table 5 shows the correlation matrix between the studied parameters, while also defining the correlation and extent between the associated parameters. Accordingly, residual chlorine had significant, positive correlations with turbidity (0.71) and total hardness (0.69). On the other hand, turbidity only had a significant, positive correlation with total hardness (0.62), while pH had a significant, negative correlation with electrical conductivity (-0.59). In addition, TDS had a significant, positive correlation with electrical conductivity (0.64), and a significant, positive correlation was also observed between residual chlorine and total hardness (0.45).

Table 4. One-sample t-test and comparison of mean parameters with desirable and standard values

Parameter	Standard	Range	Storage tank			Distribution network		
			T value	Sig.	Description	t-test	Sig.	Explanation
Turbidity	Iran	Desirable	P>0.05 -8.242	0.000	Significant, less than desirable value	P>0.05 -15.580	0.000	Significant, less than desirable value
		Allowable	P>0.05 -117.968	0.000	Significant, less than allowable value	P>0.05 -185.53	0.000	Significant, less than desirable value
	WHO	Desirable	P>0.05 - 2.901	0.000	Significant, higher than desirable value	P>0.05 5.574	0.000	Significant, higher than desirable value
		Allowable	P>0.05 -117.968	0.000	Significant, less than allowable value	P>0.05 -158.532	0.000	Significant, less than desirable value
	EPA	Allowable	P>0.05 -117.968	0.000	Significant, less than allowable value	P>0.05 -185.532	0.000	Significant, less than desirable value
TDS	Iran	Desirable	P>0.05 -68.020	0.000	Significant, less than desirable value	P>0.05 -120.367	0.000	Significant, less than desirable value
		Allowable	P>0.05 -117.968	0.000	Significant, less than allowable value	P>0.05 -208.092	0.000	Significant, less than desirable value
	WHO	Desirable	P>0.05 -28.318	0.000	Significant, less than desirable value	0 P>0.05 -50.186	0.000	Significant, less than desirable value
		Allowable	P>0.05 - 68.020	0.000	Significant, less than allowable value	P>0.05 -120.367	0.000	Significant, less than desirable value
	EPA	Allowable	P>0.05 -11.392	0.000	Significant, less than allowable value	P>0.05 -32.641	0.000	Significant, less than desirable value
EC	Iran	Desirable	P>0.05 -46.199	0.000	Significant, less than desirable value	P>0.05 -81.444	0.000	Significant, less than desirable value
Chloride	Iran	Desirable	P>0.05 -39.102	0.000	Significant, less than desirable value	P>0.05 -128.245	0.000	Significant, less than desirable value
		Allowable	P>0.05 -72.776	0.000	Significant, less than allowable value	P>0.05 -49.124	0.000	Significant, less than desirable value
	WHO	Allowable	P>0.05 -27.877	0.000	Significant, less than desirable value	P>0.05 -68.904	0.000	Significant, less than desirable value
		Allowable	P>0.05 -39.102	0.000	Significant, less than allowable value	P>0.05 P>0.05 -68.904	0.000	Significant, less than desirable value
	EPA	Allowable	P>0.05 -39.102	0.000	Significant, less than desirable value	P>0.05 -68.904	0.000	Significant, less than desirable value
Total hardness	Iran	Desirable	P>0.05 3.787	0.001	Significant, higher than desirable value	P>0.05 -6.698	0.000	Significant, higher than desirable value
		Allowable	P>0.05 -29.43	0.000	Significant, less than allowable value	P>0.05 -51.94	0.000	Significant, less than desirable value
	WHO	Desirable	P>0.05 3.787	0.001	Significant, higher than desirable value	P>0.05 6.698	0.000	Significant, higher than desirable value
		Allowable	P>0.05 -1.750	0.096	Significant, less than allowable value	P>0.05 -12.848	0.000	Significant, less than desirable value
Total coliform	Iran	Desirable	-	-	-	P>0.05 1.426	0.159	Significant, higher than desirable value
	WHO	Desirable	-	-	-	P>0.0 1.426	0.159	Significant, higher than desirable value
	EPA	Desirable	-	-	-	P>0.05 1.426	0.159	Significant, higher than desirable value
Fecal coliform	Iran	Desirable	-	-	-	P>0.05 2.659	0.010	Significant, higher than desirable value
	WHO	Desirable	-	-	-	P>0.05 -2.659	0.010	Significant, higher than desirable value
	EPA	Desirable	-	-	-	P>0.05 2.659	0.010	Significant, higher than desirable value

Table 5. Correlation matrix of studied parameters based on distribution networks (*P<0.01)

		Residual chlorine	Temperature	Turbidity	pH	TDS	EC	Chloride	Total ardness
Residual chlorine	Correlation	1							
Turbidity	Correlation	0.712**	0.287	1					
pH	Correlation	-0.302	-0.087	-0.394	1				
TDS	Correlation	0.403	-0.150	0.318	-0.306	1			
EC	Correlation	0.312	-0.101	0.167	-0.59**	0.646**	1		
Chloride	Correlation	0.322	0.326	0.140	-0.282	0.048	0.231	1	
Total hardness	Correlation	0.695**	0.180	0.620**	-0.140	0.120	0.072	0.458*	1

Table 6 shows the correlation matrix of the studied parameters. Accordingly, residual chlorine had significant, negative correlations with pH (-0.36), total coliforms (-0.62), and fecal coliforms (-0.35), while it had a positive correlation with total hardness (0.52). Moreover, turbidity was positively and significantly correlated with TDS (0.31), total hardness (0.49), and total coliforms (0.48).

According to the results of the present study, pH had significant, negative correlations with electrical conductivity (-0.55), TDS (-0.26), and chloride (-0.30), while it had significant, positive correlations with total coliforms (0.28) and fecal coliforms (0.36). The same correlation was observed between TDS and electrical conductivity (0.64). Additionally, chloride had a significant, positive correlation with total hardness (0.45), while total coliforms had a significant, positive correlation with fecal coliforms (0.73).

Table 6. Correlation matrix of investigated parameters based on distribution networks (**P<0.01)

		Residual chlorine	Temperature	Turbidity	pH	TDS	EC	Chloride	Total hardness	Total coliform	Fecal coliform
Chlorine	Correlation	1									
Turbidity	Correlation	0.156	0.451**	1							
pH	Correlation	-0.36**	0.064	-0.185	1						
TDS	Correlation	0.251	-0.004	0.315*	-0.261*	1					
EC	Correlation	0.222	-0.056	0.152	-0.55**	0.645**	1				
Chloride	Correlation	0.230	0.221	0.083	-0.302*	0.054	0.235	1			
Total hardness	Correlation	0.522**	0.138	0.498**	-0.185	0.127	0.076	0.457**	1		
Total coliform	Correlation	-0.62**	0.639**	0.482**	0.283*	0.062	-0.048	-0.096	-0.126	1	
Fecal coliform	Correlation	-0.35**	0.298*	0.246	0.365**	-0.121	-0.109	-0.238	-0.233	0.734**	1

According to the current research, the values of electrical conductivity, total hardness, residual chlorine, pH, and TDS in the storage tanks and distribution networks were in accordance with the Iranian, WHO, and USEPA standards. Furthermore, the total and fecal coliforms in the storage tanks were entirely in accordance with the national, WHO, and USEPA standards. In the distribution networks, the total coliform and fecal coliform indices were observed to be higher than the national and international standards (WHO and USEPA) in 11.67 and 3.33% of the samples, respectively.

Based on the Iranian drinking water standards, the desirable value of free residual chlorine in the network after 30 min of contact time was 0.5-0.8 mg/L in normal conditions based on pH, while it should be 1 mg/L in emergencies with the higher prevalence of intestinal diseases and natural disasters. Among the studied villages of Saqqez, the residual chlorine in the storage tanks was out of the standard range in 15% of the samples, while in the distribution networks, the value was out of the standard range in 25.03% of the samples, and only 1.66% of the samples had no chlorine. One of the main reasons for the reduction of residual chlorine from the storage tanks to the distribution networks could be the distance from chlorination sites (i.e., storage tanks).[17]

Majdi *et al.* conducted a study on the drinking water distribution networks in the villages of Takab (Iran), observing that residual chlorine in 67.7% of the samples was within the recommended range of the Iranian national standards, while it was above or below the standard limit in 33.3% of the samples. In the mentioned study, the water in 12.3% of the villages had coliform contamination, and the mean fecal coliform was 3.0351±0.74 (maximum: 240, minimum: zero). The mean hardness was 2447±11.02 $CaCO_3$ mg/L, and significant correlations were also reported between residual chlorine and total and fecal coliforms (P<0.001). In other words, increases residual chlorine was associated with the reduction of residual coliform contamination.[17] In the present study, the correlation-coefficient was negative between residual chlorine and total and fecal coliforms in the water resources of the studied villages. In the research by Majdi *et al*., the increased residual chlorine content resulted in the significant reduction of total and fecal coliform contamination.[17]

In another study, Shabankareh Fard *et al*. investigated the physical, chemical, and microbial quality of the drinking water distribution networks in Bushehr (Iran), reporting the residual chlorine of 0.6, pH of 7.22-7.40, electrical conductivity of 1,108.2-1,218 (mean: 1,155.5), turbidity of 0.5-0.8 (mean: 0.27), and mean total hardness of 458.[18] These findings are consistent with the current research in terms of residual chlorine, pH, and turbidity, while inconsistent in terms of total hardness and electrical conductivity as the distribution networks of the villages in Saqqez had lower mean values comparatively.

In another study, Robat Sarpoushi *et al*. surveyed the microbial and chemical quality of drinking water in Rabat-e-Sarpoush and Shamegan villages in Sabzevar (Iran), reporting that compared to the Iranian national standards, pH was 7.6-8.6. Moreover, out of 18 villages, the value of residual chlorine was zero in 11% of the villages, which was higher than 0.8 in 16.6% of the villages. Moreover, coliform was observed in 9.6% of the villages, and hardness was higher than the acceptable level in 11% of the samples. Chloride was also higher than the acceptable level in 39% of the samples.[19]

In the villages of Saqqez in the present study, residual chlorine was observed to be higher than the maximum permissible level in 8.33% of the samples from the distribution networks, while it was zero in only 1.66% of the samples. On the other hand, chlorine and hardness were within the national standards in 100% of the samples. In the villages of Saqqez, residual chlorine in 85% of the samples obtained from the storage tanks was within the standard range, while such finding was not observed in 15% of these samples, and the values were higher or lower than the standard limits (no zero observed). Therefore, all the microbial tests of the storage tank samples were negative, while in the distribution networks, 74.97% of residual chlorine measurements were within the standard range. In addition, 88.33% of the total coliforms and 96.66% of the fecal coliforms were within the national, WHO, and USEPA standards.

In the study by Habuda- Stanić *et al*., the microbiological quality of drinking water was investigated in 25 public water supply systems in the Osijek-Baranja area, located in eastern Croatia, and total coliforms and *E. coli* were observed in 3.9 and 1% of the samples, respectively. Moreover, the most significant, negative correlation was observed between microbial population and residual free chlorine concentration, while a positive correlation was reported between turbidity and microbial population. Total coliforms were also observed in 149 out of 1,503 samples, and reduced pH was associated with increased fecal coliform growth.[20]

According to our findings in the villages of Saqqez city, total and fecal coliforms were positively correlated with turbidity (fecal coliforms: 0.246, total coliforms: 0.482) in the distribution networks, while a negative correlation was denoted between total and fecal coliforms (fecal coliforms: -0.35, total coliforms: -0.62). In a research in this regard, Hoxha and Hamzaraj assessed the quality of drinking water in 13 rural office units and compared the results with the WHO standards. Out of 433 samples in the mentioned study, 5.7% of the samples had fecal index contamination, 6.21% showed at least one positive fecal index, and 3.5% of the samples (n=15) were positive in terms of three fecal indices. Furthermore, 6.21% of the samples were positive for *E. coli*, while only 3.71% were positive in terms of the fecal index.[21]

According to the survey of the villages in Saqqez in the current research, the values of pH, TDS, electrical conductivity, and chloride in the distribution networks were within the WHO standard ranges in 100% of the samples. In a similar study, Ahmad *et al*. examined the residual chlorine changes in the water distribution system, as well as the association of residual chlorine with total and fecal coliforms in Gwalior (Madhya Pradesh, India). In total, 56 samples were collected from 11 sites, and the results revealed that residual chlorine was within the range of 0.8-0.88, and the total coliforms in most of the sampling sites was within the range of 0.82-82.15. In addition, residual chlorine in water significantly decreased over time, thereby leading to colossal microbial growth. In the sites that were in the proximity of treatment plants, the least total and fecal coliforms were observed.[22]

According to our findings in the villages of Saqqez, the total and fecal coliforms were zero at the beginning of the distribution networks where the residual chlorine was within the standard range. However, the contamination was mostly observed at the endpoints of the distribution networks where the level of residual chlorine decreased. In another study conducted by Fazli *et al*., the microbial status of drinking water was investigated in the urban and rural distribution systems in Ijroud in Zanjan province. In the mentioned research, 66.66% of the samples were positive for total and fecal coliforms. Moreover, significant differences were observed between proper microbial quality and residual chlorine in drinking water ($P<0.05$). Out of the 15 studied facilities, the samples obtained from only five facilities or five villages had no fecal coliforms (range: 4-75; relatively high maximum), while in some villages, coliform contamination was less than 10. In such circumstances, these pollutants could be eliminated without causing any harm to the users through the appropriate chlorination of water.[13]

In the villages of Saqqez in the present study, the results were better in terms of total and fecal coliform contamination due to the proper fencing around the drinking water wells and proper distance from contamination sources, so that fecal coliform contamination in the drinking water supplies was observed in 14.28% of the total source supplies. The minimum and maximum contamination rates were 3 and 9 MPN, respectively, which could be eliminated through appropriate chlorination. In the present study, along with the distribution networks, a slight reduction was observed in residual chlorine due to distance from the chlorination site. On the other hand, the mean turbidity value had a partial increasing trend from the storage tanks to the distribution networks, which was associated with the reduction of residual chlorine from the storage tanks to the distribution networks.

According to the findings of the current research, the mean pH, residual chlorine, and total hardness had no changes from the storage tanks to the distribution networks, which revealed that chlorination had no effects on the levels of these parameters. However, the mean TDS and electrical conductivity slightly decreased from the storage tanks to the distribution networks. The mean total coliforms in the storage tanks was zero, while it was 0.48 in the distribution networks, demonstrating the promising effects of chlorination on the total coliforms in the storage tank and its re-increase in the distribution networks due to the reduction of the free residual chlorine throughout the network and possible fractures in the distribution networks (secondary contamination). Finally, the mean fecal coliform count was zero in the storage tanks and 0.1 in the distribution networks.

Conclusion

According to the results, all the examined parameters were in compliance with the national and international standards, and the drinking water in most of the cases posed no particular risks to the consumers.

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