Research Paper

The role of decentralized municipal desalination plants in removal of physical, chemical and microbial parameters from drinking water: a case study in Bushehr, Iran

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ABSTRACT

The aim of this study was to evaluate the role of decentralized municipal desalination plants in removal of physical, chemical and microbial parameters from drinking water in Bushehr, Iran and compare the quality of outlet water with guidelines for drinking water. Fifty samples were taken from 10 decentralized municipal desalination plants (five times from every station). The mean values of physical, chemical and microbial parameters in outlet water were electrical conductivity (322.08 μS/cm), turbidity (0.0 NTU), pH (6.84), alkalinity (61.2 mg/L), carbonate (0 mg/L), bicarbonate (61.2 mg/L), total hardness (82.96 mg/L), calcium hardness (73.8 mg/L), magnesium hardness (18.96 mg/L) as $CaCO_3$, calcium (29.52 mg/L), magnesium (4.72 mg/L), residual chlorine (0.37 mg/L), chloride (25.61 mg/L), TDS (161.04 mg/L), iron (0.045), fluoride (0.167 mg/L), nitrate (1.71 mg/L), nitrite (0.0026 mg/L), sulphate (107.17 mg/L), total coliform (0), fecal coliform (0) (MPN/100 mL) and HPC (322.9 CFU/mL). Our results showed that 10% of HPC outlet samples did not comply with the Iranian National Regulation (INR), Environmental Protection Agency (EPA), and World Health Organization (WHO) guidelines. The mean levels of examined parameters in desalination plants' outlets generally complied with the INR, EPA and WHO guidelines. Decentralized municipal desalination plants efficiency in removal of measured parameters were in the range of 18.52 (in the case of nitrite) to 100% (in the case of turbidity).

Key words | Bushehr, decentralized municipal desalination plants, drinking water guidelines, water treatment

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INTRODUCTION

Availability of safe and high-quality water has been an objective of human society going back to prehistoric times (Calderon 2000; Mara 2003; Völker *et al.* 2010; Fard *et al.* 2015; Raeisi *et al.* 2017). Water is a fundamental natural resource for the sustainability of life on earth (Binghui *et al.* 2006; WHO 2011), but when polluted it may become the source of undesirable substances dangerous to human health (Mancini *et al.* 2005). Access to adequate water and assurance of its safety are the most significant concerns of health authorities (Ozaki & Li 2002; Fahiminia *et al.* 2014).

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Throughout the world, especially in the Middle East, the deterioration in quality of available water and water shortages is increasing (Yassin *et al.* 2006; Almasri 2008). Today, 450 million people in 29 countries suffer from water deficiency (Güler 2007). Physical, chemical and microbial parameters of drinking water may affect its safety and consumers' consent (Ngari *et al.* 2013). The main requirements for drinking water are that it should be free from pathogenic organisms and contain no compounds that have a harmful effect in the short or long term on human health (WHO 1998). According to the United Nations (UN), about 80% of infant mortality worldwide occurs due to gastrointestinal diseases such as diarrhea (Gasana *et al.* 2002) and over one-third of deaths in developing countries occur following the drinking of contaminated water (Balbus & Lang 2001; Al-Khatib & Arafat 2009; Nair & Kumar 2013). The most commonly used indicators for microbiological contamination are total coliform (TC) and fecal coliform (FC) (Viessman *et al.* 2009). Furthermore, the high amounts of some physical and chemical parameters such as hardness, total dissolved solids (TDS), nitrate, nitrite, pH, salinity, chloride and heavy metals in water may introduce some problems for the consumer (Gagliardo *et al.* 1998; Salehi *et al.* 2014). Hence, drinking water guidelines have been developed by national and international organizations to define limits for physical, chemical and microbial contents to ensure the required quality (Sobsey & Bartram 2002; Güler & Alpaslan 2009). Therefore, the monitoring of drinking water from source to consumption to meet drinking water guidelines is an important step towards health and safety (Völker *et al.* 2010). Various factors such as displeasure and concern about drinking water quality owing to the absence of sufficient water treatment facilities, impurity during storage and distribution, and insufficient or incorrect understanding on the part of consumers about the quality of distributed water can influence community attitudes in such a way as to cause them to substitute or change their drinking water sources (Beverage Marketing Corporation of New York 2006). Decentralized municipal desalination plants play an important role in providing healthy drinking water based on qualitative standards. The increasing trend of water consumption and decrease of natural sources of fresh water make this role even more important. Since the control of drinking water is of great importance in terms of health, this research was carried out to determine the role of decentralized municipal desalination plants in the removal of physical, chemical and microbial parameters of drinking water in Bushehr, Iran; it also sought to compare the quality of outlet water from these plants with Iranian National Regulation (INR), US Environmental Protection Agency (EPA) and World Health Organization (WHO) guidelines for drinking water. Finally, we calculated daily intakes of different anions and cations.

MATERIALS AND METHODS

Drinking water source and study area

The Kosar dam is located at a distance of 60 km northwest of Dogonbadan, in the city of Gachsaran in Kohgiluyeh and Boyer-Ahmad Province, which was built on the Kheirabad river. The physicochemical parameter values of the Kosar dam are shown in Table 1. The Bushehr regional water authority uses this dam's water as the main source of drinking water in Bushehr city.

Table 1 | Values for physicochemical parameters of Kosar dam

Parameter	Unit	Value
EC	μS/cm	1366
pH	–	7.8
Turbidity	NTU	0.93
Residual-chlorine	mg/L	0
TDS	mg/L	1093
Ca^{2+}	mg/L	202
Mg^{2+}	mg/L	21.5
Cl^-	mg/L	154
Fe	mg/L	0.02
F^-	mg/L	0.61
NO_3^-	mg/L	3.96
NO_2^-	mg/L	0.003
SO_4^{2-}	mg/L	410
Alkalinity	mg/L as $CaCO_3$	124
Bicarbonate	mg/L as $CaCO_3$	124
Total hardness	mg/L as $CaCO_3$	592
Ca hardness	mg/L as $CaCO_3$	468
Mg hardness	mg/L as $CaCO_3$	124

Water samples were collected from 10 sampling sites (including Helali (S1), Shekari (S2), Sangi (S3), Sartol (S4), Rishehr (S5), Bahmani (S6), Mir Alamdar (S7), Ashori (S8), Solh Abad (S9), and Bagh Zahra (S10)), which were located in Bushehr city. The locations of the Kosar dam and the sampling points are shown in Figure 1.

Sample collection and physicochemical analysis

In this cross-sectional study, 50 samples were taken from 10 decentralized municipal desalination plants (five times from each plant) working by a process of reverse osmosis (RO) in Bushehr, Iran. Details of the decentralized municipal desalination plants are shown in Table 2. Representation of a typical RO facility is shown in Figure 2. Physicochemical samples were collected in plastic containers. Electric conductivity (EC) and turbidity were measured using a Greisinger-GLM020 electrical conductivity meter and LUTRON-2016 turbidity meter (with an MDL value of 0.01 NTU), respectively. Residual chlorine levels and pH values were measured using a DPD colorimetric kit test and a pH meter, respectively. Hardness and chloride were measured according to the standard method (APHA 2008). Spectrophotometric methods were used for analyses of F^- (570 nm), Fe^{2+} (510 nm), NO_2^- (507 nm), NO_3^- (400 nm), SO_4^{2-} (450 nm) and PO_4^{2-} (890 nm), using a DR/2000 spectrophotometer (HACH Company, USA).

Microbial analaysis

All microbial samples were collected in 250 mL sterile containers, placed in an ice box at 4 °C, and immediately transported to the laboratory for analysis. To determine heterotrophic bacteria, a heterotrophic plate culture technique following the standard method was used (APHA 2008). A 0.1 mL sample water was spread on to R2A agar plate and incubated at 35 °C for 48 h and colonies were counted by using a Scan 100 Interscience colony counter with results reported as CFU/mL. For TC and FC analyses, 100 mL of collected sample was subjected to a multiple-tube5 fermentation method. Lactose Broth and Brilliant Green Bile Lactose were used for the determination of total coliform (incubated at 35.5 ± 0.5 °C for 48 h), while Brilliant Green Bile Lactose was used for the determination of fecal coliform (incubated at 44.5 ± 0.2 °C for 24 h) and the results were reported as the most probable number per 100 mL (MPN/100 mL).

Data analysis

Statistical analyses were carried out using Microsoft Excel 2013. The results were expressed as mean ± SD and the mean value of each parameter was compared to drinking water guidelines.

RESULTS

The EPA, WHO and INR guideline values for physicochemical and microbial parameters of drinking water are presented in Table 3.

Tables 4–6 show the measured physicochemical parameters of decentralized municipal desalination plant outlets, removal percentage (%), while Tables 4 and 5 also show the calculated daily intakes (mg/day) of different anions and cations. The minimum, maximum, and mean concentration levels of Ca^{2+} in the outlet waters were 12.16, 48.16, and 29.52 mg/L, respectively. Calcium in the outlet waters decreased by 81.11% compared to the inlet waters. As seen in Table 4, the maximum daily intakes of calcium based on 2 L daily drinking water consumption (Valtin 2002) reached 59.04 with a range of 24.32–96.32 mg/day. The mean concentration level of Mg^{2+} was 4.72 mg/L as $CaCO_3$ with a range of 2.99–6.58 mg/L in the outlet waters. Magnesium in the outlet waters decreased by 72.86% compared to the inlet waters, and outlet water levels were in the standard range. The maximum daily intakes of Mg^{2+} based on 2 L daily drinking water consumption reached 9.45 with a range of 6.58–13.16 mg/day. The mean concentration levels of calcium and magnesium hardness in the outlet waters ranged from 30.4 to 120.4 (mean: 73.8) and 12–26.4 (18.96) mg/L as $CaCO_3$, respectively. Calcium and magnesium hardness in the outlet waters decreased by 81.12 and 72.12% compared to the inlet waters, respectively. In the outlet sections of all decentralized municipal desalination plants, the calcium and magnesium hardnes values were compatible with drinking water standards. The concentration level of total hardness in this study was found to be

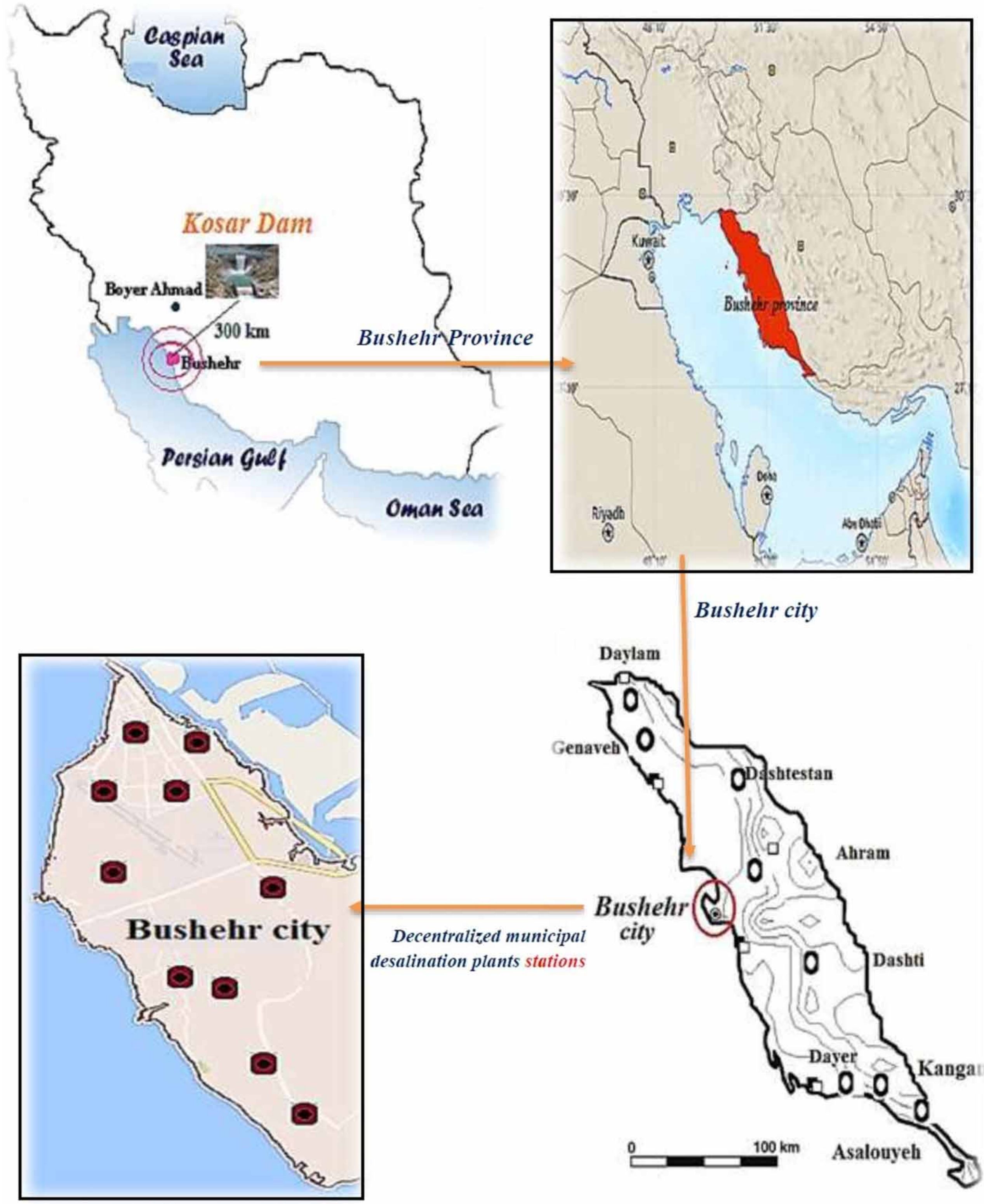

Figure 1 | Locations of sampling stations in the study area.

Table 2 | Decentralized municipal desalination plant details and comparison of the costs of other water supplies with these devices

Stations	Flow rate	Filter replacement period (month)	Treatment methods	Type of RO membranes	Manufacturer of RO membranes
S1 (Helali)	24 m^3/day	2	RO process	Cellulose acetate	Pooya-tasfiye/Iran
S2 (Shekari)	10 m^3/day	6	RO process	Cellulose acetate	Pooya-tasfiye/Iran
S3 (Sangi)	10 m^3/day	12	RO process	Cellulose acetate	Pooya-tasfiye/Iran
S4 (Sartol)	15 m^3/day	6	RO process	Cellulose acetate	Parsian-farab/Iran
S5 (Rishehr)	10 m^3/day	3	RO process	Cellulose acetate	Parsian-farab/Iran
S6 (Bahmani)	15 m^3/day	3	RO process	Cellulose acetate	Absun/Iran
S7 (Mir Alamdar)	15 m^3/day	6	RO process	Cellulose acetate	Omransazan-mahab/Iran
S8 (Ashori)	4 m^3/day	6	RO process	Cellulose acetate	Omransazan-mahab/Iran
S9 (Solh Abad)	20 m^3/day	12	RO process	Cellulose acetate	Absun/Iran
S10 (Bagh Zahra)	10 m^3/day	1	RO process	Cellulose acetate	Parsian-farab/Iran
Economics of drinking water supplies					
Cost of drinking water in distribution system[a] (cent/m^3) 13.5					
Cost of water treatment by decentralized municipal desalination plants[b] (\$/m^3) 3.78					
Price of water after treatment in decentralized municipal desalination plants (\$/m^3) 13.51					
Price of bottled water (cent/lit)[c] 18					

[a]The cost of every m^3 of drinking water in distribution systems for public consumption is 13.5 cents. Decentralized municipal desalination plants use drinking water in distribution systems as their feeding water and the cost of this water is 37.84 cent/m^3.
[b]Based on all costs including electricity consumption, buying water, filter replacement, system maintenance, etc.
[c]180 \$/m^3.

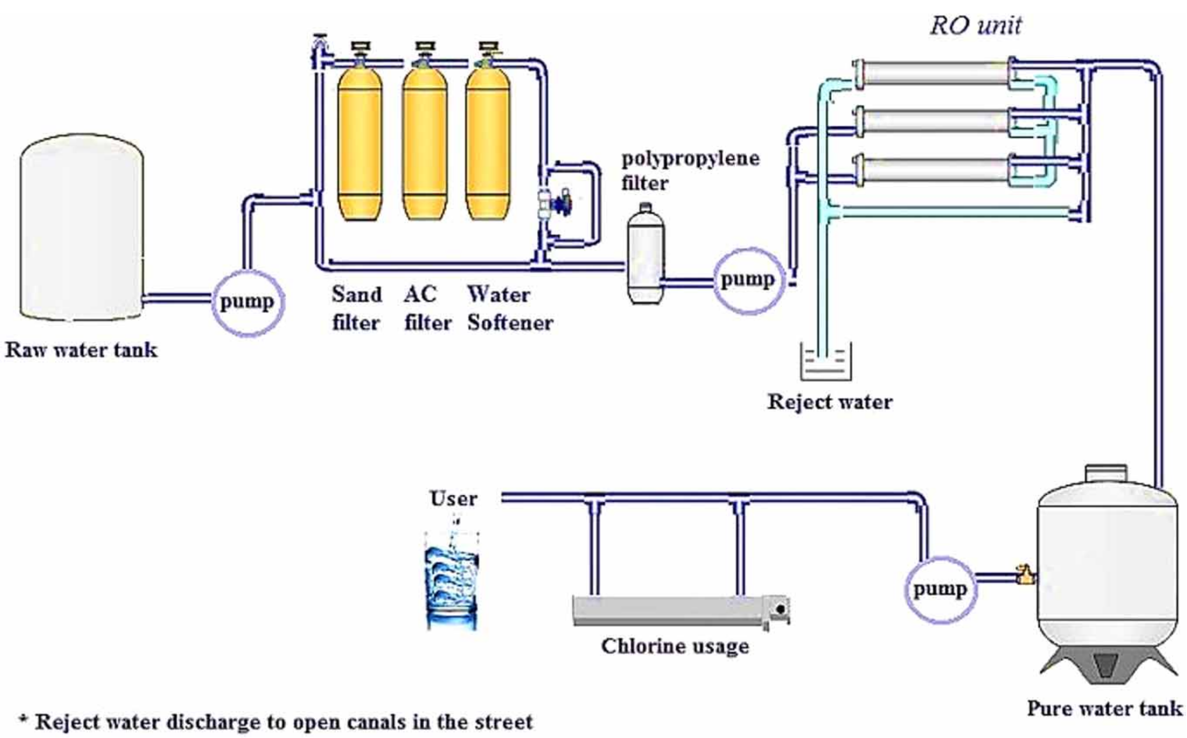

Figure 2 | Schematic of typical RO system in decentralized municipal desalination plants in Bushehr.

Table 3 | EPA, WHO, and INR guidelines for drinking water

		Drinking water quality guidelines		
Parameter	**Unit**	**EPA**[a]	**WHO**[b]	**INR**[c]
EC	μS/cm	*	*	1500
pH	–	6.5–8.5	*	6.5–9
Turbidity	NTU	5	*	5
Residual-chlorine	mg/L	*	*	*
TDS	mg/L	500	500	1500
Ca^{2+}	mg/L	*	*	*
Mg^{2+}	mg/L	30[#]	*	*
Cl^{-}	mg/L	250	*	400
Fe	mg/L	0.3	*	0.3
F^{-}	mg/L	4	1.5	1.5
NO_3^{-}	mg/L	45	50	50
NO_2^{-}	mg/L	0.3	3	3
SO_4^{2-}	mg/L	250	*	*
Alkalinity	mg/L as $CaCO_3$	*	*	*
Bicarbonate	mg/L as $CaCO_3$	*	*	*
Total hardness	mg/L as $CaCO_3$	*	*	500
Ca hardness	mg/L as $CaCO_3$	*	*	250
Mg hardness	mg/L as $CaCO_3$	*	*	50
Total coliform	MPN/100 mL	0	0	0
Fecal coliform	MPN/100 mL	0	0	0
HPC	CFU/mL	500	500	500

[a]US EPA guideline for drinking water (maximum admissible concentration).
[b]WHO guideline for drinking water (maximum admissible concentration).
[c]INR guideline for drinking water (maximum admissible concentration).
*Not determined,
[#]Desirable admissible concentration.

between 13.96 and 141.2 mg/L as $CaCO_3$ with a mean concentration level of 82.96 mg/L as $CaCO_3$ in the outlet waters. The maximum daily intakes of total hardness based on 2 L daily drinking water consumption reached 147.6 with a range of 60.8–240.8 mg/day. The mean concentration level of alkalinity was 61.2 mg/L as $CaCO_3$ with a range of 36–88 mg/L as $CaCO_3$ in the outlet waters. Analyses of carbonate and bicarbonate showed that the amount of CO_3^{2-} in all samples was equal to zero (0 mg/L as $CaCO_3$) and the concentration level of HCO_3^{-} was 36–88 (mean: 61.2) mg/L as $CaCO_3$ in the outlet waters. Alkalinity and bicarbonate in the outlet waters decreased by 64.31% compared to the inlet waters. The concentration levels of nitrate and nitrite in the outlet waters ranged from 0.77 to 2.47 (mean: 1.71) and 0.002–0.003 (mean: 0.0026) mg/L, respectively. Nitrate and nitrite in the outlet waters decreased by 44.48 and 18.52%, respectively, compared to the inlet waters. The maximum daily intakes of nitrate and nitrite based on 2 L daily drinking water consumption reached 88.62 and 0.0054 with a range of 38.56–148.58 and 0.004–0.01 mg/day respectively. Analysis of residual chlorine showed that the mean concentration level of this parameter was 0.42 mg/L with a range of 0.24–0.52 mg/L in the outlet waters. The removal percentage of residual chlorine in the outlet waters was 42.72% compared to the inlet waters. The mean concentration level of iron was 0.045 with a range of 0.04–0.07 mg/L in the outlet waters. Iron in the outlet waters decreased by 63.71% compared to the inlet waters. The maximum daily intakes of Fe based on 2 L daily drinking water consumption reached 0.102 with a range of 0.08–0.24 mg/day. The concentration level of fluoride in this study was found to be between 0.07 and 0.26 mg/L with a mean concentration level of 0.167 mg/L in the outlet waters. The removal percentage of fluoride in the outlet waters was 65.21% compared to the inlet waters. The maximum daily intakes of fluoride based on 2 L daily drinking water consumption reached 0.334 with a range of 0.14–0.52 mg/day. The minimum and maximum concentrations of sulfate ion were 44.54 and 144.99 with a mean concentration level of 107.17 mg/L in the outlet waters. Sulfate in the outlet waters decreased by 85.29% compared to the inlet waters. The maximum daily intakes of sulfate based on 2 L daily drinking water consumption reached 214.34 with a range of 89.08–289.98 mg/day. The minimum and maximum concentration levels of chloride ion were found to be between 12.19 and 38.58 with a mean concentration level of 82.26 mg/L in the outlet waters. Chloride in the outlet waters decreased by 68.87% compared to the inlet waters. The maximum daily intakes of chloride based on 2 L daily drinking water consumption reached 51.22 with a range of 24.38–77.16 mg/day. The minimum and maximum level values of pH were found to be between 6.8 and 6.96 with a mean level value of 6.84 in the outlet waters. pH in the outlet waters decreased by 3.93% compared to the inlet waters. The results showed that decentralized municipal desalination plants could remove up to 100% turbidity from input water. So, the mean level value of turbidity reached zero in the outlet waters. The mean

Table 4 | Mean level values of the measured physicochemical parameters in the outlet waters of decentralized municipal desalination plants, removal percent (%) and daily intake (mg/day)

	Ca^{2+} (mg/L)			Mg^{2+} (mg/L)			SO_4^{2-} (mg/L)		
Station	**Outlet**	**Removal (%)**	**Daily intake[a]**	**Outlet**	**Removal (%)**	**Daily intake**	**Outlet**	**Removal (%)**	**Daily intake**
1	29.28 ± 2.86	80.30	58.56	3.89 ± 1.19	77.45	7.78	122.83 ± 23.23	82.10	245.66
2	48.16 ± 4.53	68.08	96.32	5.18 ± 1.67	65.14	10.36	144.99 ± 45.99	77.89	289.98
3	36.64 ± 3.36	75.56	73.28	5.08 ± 1.29	69.12	10.16	136.48 ± 29.93	79.21	272.96
4	20.32 ± 2.86	86.19	40.64	4.68 ± 1.85	72.06	9.36	88.58 ± 6.91	86.02	177.16
5	35.36 ± 2.61	77.33	70.72	6.38 ± 0.73	60.03	12.76	131.82 ± 24.95	80.63	263.64
6	35.2 ± 1.6	78.49	70.4	6.58 ± 6.1	62.29	13.16	92.02 ± 7.3	89.76	184.04
7	12.16 ± 2.96	92.39	24.32	2.99 ± 3.66	84.94	5.98	44.54 ± 51.97	94.58	89.08
8	28.32 ± 1.55	82.66	56.65	3.89 ± 2.06	77.45	7.78	111.28 ± 17.79	86.22	222.56
9	31.36 ± 1.53	80.32	62.72	5.28 ± 5.17	75.02	10.56	124.68 ± 20.20	84.56	249.36
10	18.4 ± 3.62	88.78	36.8	3.29 ± 1.56	80.59	6.58	74.5 ± 17.9	88.28	149
Mean ± SD	**29.52 ± 10.43**	81.01	59.04	**4.72 ± 1.22**	72.86	9.45	**107.17 ± 31.68**	85.29	214.34
	F^- (mg/L)			Fe (mg/L)			Cl^- (mg/L)		
Station	**Outlet**	**Removal (%)**	**Daily intake**	**Outlet**	**Removal (%)**	**Daily intake**	**Outlet**	**Removal (%)**	**Daily intake**
1	0.18 ± 0.06	58.14	0.36	0.04 ± 0.004	66.67	0.08	24.79 ± 3.05	69.23	49.58
2	0.26 ± 0.06	40.91	0.52	0.04 ± 0.008	33.33	0.08	38.58 ± 13.99	51.39	77.16
3	0.21 ± 0.09	53.33	0.42	0.04 ± 0.001	63.64	0.08	26.99 ± 4.75	66.63	53.98
4	0.07 ± 0.04	83.33	0.14	0.04 ± 0.038	75.00	0.08	12.69 ± 2.3	84.01	25.38
5	0.13 ± 0.03	69.77	0.26	0.04 ± 0.008	88.89	0.08	26.69 ± 5.8	63.17	53.38
6	0.19 ± 0.08	63.46	0.38	0.04 ± 0.004	33.33	0.08	37.08 ± 3.47	57.99	74.16
7	0.1 ± 0.052	83.05	0.2	0.12 ± 0.14	50.00	0.24	12.19 ± 1.82	85.65	24.38
8	0.19 ± 0.09	64.81	0.38	0.04 ± 0.005	33.33	0.08	27.69 ± 3.89	67.87	55.38
9	0.19 ± 0.12	57.78	0.38	0.04 ± 0.005	0.00	0.08	22.89 ± 4.29	73.25	45.78
10	0.15 ± 0.1	70.59	0.3	0.07 ± 0.06	53.33	0.14	26.49 ± 3.85	68.82	52.98
Mean ± SD	**0.167 ± 0.05**	**65.21**	**0.334**	**0.054 ± 0.03**	63.71	**0.102**	**25.61 ± 8.58**	**68.87**	**51.22**

[a]Based on 2 liters daily drinking water consumption and concentration levels of physicochemical parameters in the outlet waters.

level value of TDS was 161.04 with a range of 64.9–239.3 mg/L in the outlet waters. TDS in the outlet waters decreased by 72.13% compared to the inlet waters. The maximum daily intakes of TDS based on 2 L daily drinking water consumption reached 322.08 with a range of 129.2–478.6 mg/day. In our study, the minimum and maximum EC was 129.2 and 478.6 μS/cm with a mean level of 322.9 μS/cm in the outlet waters. EC in the outlet waters decreased by 72% compared to the inlet waters.

The results of total coliform, fecal coliform, and HPC measurements of all samples are presented in Table 7. The results of all FC and TC measurements were negative. In other words, all of the outlet drinking water taken from the decentralized municipal desalination plants was found free from coliforms and met the INR, EPA and WHO guidelines (0 MPN/100 mL) (ISIRI 2001; WHO 2011). The minimum and maximum levels of HPC were 186 and 434 CFU/mL with a mean concentration level of 322.9 CFU/mL in outlet water samples.

Table 8 shows the distribution of HPC in the outlet drinking water taken from the decentralized municipal desalination plants. As shown in Table 8, 90% of all drinking water samples contained HPC within a range of 1–500 CFU/mL and 10% of samples contained a value

Table 5 | Mean level values of the measured physicochemical parameters in the outlet waters of decentralized municipal desalination plants, removal percentage (%) and daily intake (mg/day)

	TDS (mg/L)			Total hardness (mg/L as $CaCO_3$)			Ca hardness (mg/L as $CaCO_3$)		
Station	Outlet	Removal (%)	Daily intake[a]	Outlet	Removal (%)	Daily intake	Outlet	Removal (%)	Daily intake
1	174.4 ± 51.32	69.19	348.8	88.8 ± 10.63	79.85	177.6	73.2 ± 7.15	80.30	146.4
2	239.3 ± 40.13	57.02	478.6	141.2 ± 17.64	67.67	282.4	120.4 ± 11.34	68.08	240.8
3	199.1 ± 52.99	64.37	398.2	13.96 ± 13.19	96.83	27.92	91.6 ± 8.41	75.56	183.2
4	117.7 ± 51.51	78.76	235.4	69.6 ± 8.87	84.10	139.2	50.8 ± 7.15	86.29	101.6
5	200.2 ± 56.49	65.35	400.4	114 ± 6.63	74.89	228	88.4 ± 6.54	77.33	176.8
6	180.3 ± 34.97	70.02	360.6	114.4 ± 22.42	76.13	228.8	88 ± 4.25	78.49	176
7	64.6 ± 35.25	89.03	129.2	42.4 ± 21.23	91.15	84.8	30.4 ± 7.4	92.39	60.8
8	152.9 ± 43.89	73.68	305.8	86.4 ± 10.99	81.91	172.8	70.8 ± 3.89	82.66	141.6
9	154.3 ± 24.69	73.57	308.6	99.6 ± 21.51	79.39	199.2	78.4 ± 3.84	80.32	156.8
10	127.6 ± 40.18	79.05	255.2	59.2 ± 14.6	87.14	118.4	46 ± 9.05	88.78	92
Mean ± SD	**161.04** ± **18.95**	**72.13**	**322.08**	**92.76** ± **29.7**	**81.92**	**167.7**	**73.8** ± **26.07**	**81.12**	**147.6**

	Mg hardness (mg/L as $CaCO_3$)			NO_3 (mg/L)			NO_2 (mg/L)		
Station	Outlet	Removal (%)	Daily intake	Outlet	Removal (%)	Daily intake	Outlet	Removal (%)	Daily intake
1	15.6 ± 4.77	77.46	31.2	26.94	82.10	53.88	0.002 ± 0.001	0.00	0.004
2	20.8 ± 6.72	65.10	41.6	19.28	77.89	38.56	0.002 ± 0.0008	0.00	0.004
3	20.4 ± 5.17	69.09	40.8	21.33	79.21	42.66	0.003 ± 0.001	0.00	0.006
4	18.8 ± 7.42	72.02	37.6	66.53	86.02	133.06	0.002 ± 0.001	0.00	0.004
5	25.6 ± 2.96	60.00	51.2	36.84	80.63	73.68	0.005 ± 0.004	60.00	0.01
6	26.4 ± 24.47	62.29	52.8	36.18	89.76	72.36	0.002 ± 0.0008	0.00	0.004
7	12 ± 14.69	84.92	24	74.29	94.58	148.58	0.003 ± 0.0008	33.33	0.006
8	15.6 ± 8.29	77.46	31.2	42.40	86.22	84.8	0.003 ± 0.001	33.33	0.006
9	21.2 ± 20.76	75.00	42.4	73.81	84.56	147.62	0.003 ± 0.00	0.00	0.006
10	13.2 ± 6.26	73.81	26.4	45.54	88.28	91.08	0.002 ± 0.005	0.00	0.004
Mean ± SD	**18.96** ± **4.88**	**72.12**	**37.92**	**44.48**	**85.29**	**85.29**	**0.0026** ± **0.01**	**0.0022** ± **.0006**	**0.0054**

[a]Based on 2 L daily drinking water consumption and concentration levels of physicochemical parameters in outlet waters.

higher than 500 CFU/mL. So, 90% of samples in this study met the INR, EPA and WHO regulations (ISIRI 2001; WHO 2011). The results of HPC measurements compared with the EPA, WHO and INR guidelines are shown in Figure 3.

DISCUSSION

Calcium and magnesium cations make water hard. Calcium ions play a vital role in the physiology and biochemistry of organisms, neuromuscular excitability (decreases it), good function of the conducting myocardial system, heart and muscle contractility, intracellular information transmission and blood coagulability. Osteoporosis and osteomalacia are the most common manifestations of calcium deficiency; a less common but proved disorder attributable to Ca deficiency is hypertension. Magnesium plays a main role as a cofactor and activator of more than 300 enzymatic reactions including glycolysis, ATP metabolism, transport of elements such as Na, K and Ca through membranes, synthesis of proteins and nucleic acids, neuromuscular excitability and muscle contraction, etc. (Derry *et al.* 1990; Sauvant & Pepin 2002; Kožíšek 2003). The recommended calcium and magnesium daily intake for adults ranges between

Table 6 | Mean level values of the measured physicochemical parameters in the outlet waters of decentralized municipal desalination plants and removal percentage

	EC (μS/cm)		Residual chlorine (mg/L)		Turbidity (NTU)	
Station	**Outlet**	**Removal (%)**	**Outlet**	**Removal (%)**	**Outlet**	**Removal (%)**
1	348.8 ± 77.3	69	0.52 ± 0.11	33.33	0	100
2	478.6 ± 83.7	57	0.24 ± 0.16	57.14	0	100
3	398.2 ± 48.2	64	0.32 ± 0.14	33.33	0	100
4	235.4 ± 65.4	79	0.38 ± 0.13	45.71	0	100
5	400.4 ± 76.7	65	0.40 ± 0.22	37.50	0	100
6	360.6 ± 26.0	70	0.30 ± 0.21	44.44	0	100
7	129.2 ± 10.9	89	0.52 ± 0.12	27.78	0	100
8	305.8 ± 22.9	74	0.40 ± 0.16	41.18	0	100
9	308.6 ± 30.8	74	0.32 ± 0.13	52.94	0	100
10	255.2 ± 25.8	79	0.34 ± 0.13	51.43	0	100
Mean ± SD	322.08 ± 99.1	72	0.37 ± 0.062	45.72	0	100
	pH		**HCO_3^- (mg/L as $CaCO_3$)**		**Alkalinity (mg/l as $CaCO_3$)**	
Station	**Outlet**	**Reduction (%)**	**Outlet**	**Removal (%)**	**Outlet**	**Removal (%)**
1	6.68 ± 0.21	5.9	74 ± 32.09	58.89	74 ± 32.09	58.89
2	6.96 ± 0.13	1.1	88 ± 36.8	50.00	88 ± 36.8	50.00
3	6.92 ± 0.22	3.9	67 ± 13.96	61.05	67 ± 13.96	61.05
4	6.86 ± 0.21	3.4	44 ± 4.18	74.71	44 ± 4.18	74.71
5	6.8 ± 0.13	3.4	63 ± 8.36	62.94	63 ± 8.36	62.94
6	6.8 ± 0.21	4	76 ± 8.94	55.29	76 ± 8.94	55.29
7	6.8 ± 0.15	4.8	36 ± 8.94	78.57	36 ± 8.94	78.57
8	6.8 ± 0.16	5.8	61 ± 8.94	64.12	61 ± 8.94	64.12
9	6.8 ± 0.13	5	52 ± 8.36	69.59	52 ± 8.36	69.59
10	6.8 ± 0.13	5	51 ± 5.47	68.90	51 ± 5.47	68.90
Mean ± SD	6.83 ± 0.062	4.23	61.2 ± 15.84	64.31	61.2 ± 15.84	64.31

700–1,000 and 300–400 mg, respectively (Committee on Dietary Reference Intake 1997; Sauvant & Pepin 2002). In the present study, the mean concentration levels of calcium and magnesium hardness in the outlet waters were compatible with drinking water standards. The total hardness of water may range from trace amounts to hundreds of milligrams per liter (Saleh *et al.* 2001). EPA and WHO have not set a guideline value for total hardness, but the INR has set a guideline value of 500 mg/L as $CaCO_3$ for total hardness in drinking water (ISIRI 1999). High concentration levels of nitrate and nitrite in water or food can affect the health of consumers, especially in the case of children (Fard *et al.* 2015). In the outlet waters of all decentralized municipal desalination plants, the values of nitrate and nitrite were compatible with drinking water guidelines. The presence of chlorine residual in drinking water indicates that: (1) a sufficient amount of chlorine is in the water to inactivate the bacteria and some viruses that cause diarrheal disease; and (2) the water is protected from recontamination and biofilm formation during storage and distribution (LeChevallier *et al.* 1988). Residual chlorine is present in the most disinfected drinking water at a concentration level of 0.2–1 mg/L (White 1975), but Ridgway *et al.* (1984) found that a residual of 15–20 mg of chlorine per liter was necessary to control biofilm fouling on reverse osmosis membranes. INR, EPA and WHO have not set guideline values for residual chlorine.

Table 7 | Measured microbial parameters (Mean ± SD) for the outlet drinking water collected from the decentralized municipal desalination plants

	Microbiological properties for the outlet water		
Stations	**Total coliform (MPN/100 mL)**	**Fecal coliform (MPN/100 mL)**	**HPC (CFU/mL)**
1	0 ± 0.0	0 ± 0.0	432 ± 238.15
2	0 ± 0.0	0 ± 0.0	410 ± 254.26
3	0 ± 0.0	0 ± 0.0	286 ± 185.55
4	0 ± 0.0	0 ± 0.0	434 ± 463.17
5	0 ± 0.0	0 ± 0.0	254 ± 90.71
6	0 ± 0.0	0 ± 0.0	300 ± 100.99
7	0 ± 0.0	0 ± 0.0	205 ± 148.74
8	0 ± 0.0	0 ± 0.0	186 ± 46.15
9	0 ± 0.0	0 ± 0.0	356 ± 167.72
10	0 ± 0.0	0 ± 0.0	364 ± 322.84
Mean ± SD	0 ± 0.0	0 ± 0.0	322.9 ± 90.89

Table 8 | Distribution of HPC bacteria counts for the outlet drinking water taken from the decentralized municipal desalination plants

HPC (CFU/mL)	**Number of positive sample (percentage of positive sample)**
<1	0 (0.0%)
1–500	45 (90%)
>500	5 (10%)
Range	30–1,200
Mean ± SD	322.9 ± 90.89

EPA and INR set a 0.3 mg/L guideline value for iron in drinking water (White 1975; Ridgway *et al.* 1984; LeChevallier *et al.* 1988; ISIRI 1999; EPA 2012). Exposure to excess iron levels may be a cause of a wide range of common diseases, and also may cause corrosion of the pipes in the drinking water distribution network (WHO 2011). All results of iron measurements in this study met the INR and EPA guidelines. Fluoride at elevated levels can have adverse effects on human health. In terms of general health, in communities where drinking water and foodstuffs are excessively high in fluoride, skeletal fluorosis and bone fractures are the most relevant adverse effects (Browne *et al.* 2005). Fluoride is widely distributed in the environment and is therefore of special interest. Excess fluoride intake can cause a wide range of adverse health effects (Shivarajashankara *et al.* 2001; Dobaradaran *et al.* 2008a, 2008b; Spittle 2008; Rahmani *et al.* 2010; Ostovar *et al.* 2013). In this regard, various studies in Iran have reported the occurrence of high fluoride concentration levels in drinking water (Dobaradaran *et al.* 2008a, 2008b, 2009a, 2009b; Shams *et al.* 2012; Nabipour & Dobaradaran 2013; Akhavan *et al.* 2016; Karbasdehi *et al.* 2016), air, fish and the sea (Dobaradaran *et al.* 2009a, 2009b, 2011; Nabipour & Dobaradaran 2010; Soleimani *et al.* 2017), as well as in connection with its removal from elevated fluoride waters (Boldaji *et al.* 2009; Shams *et al.* 2013; Dobaradaran *et al.* 2014, 2015, 2016; Zazouli *et al.* 2014; Keshtkar *et al.* 2016). In this study the fluoride level in the treated water was lower than the guidelines.

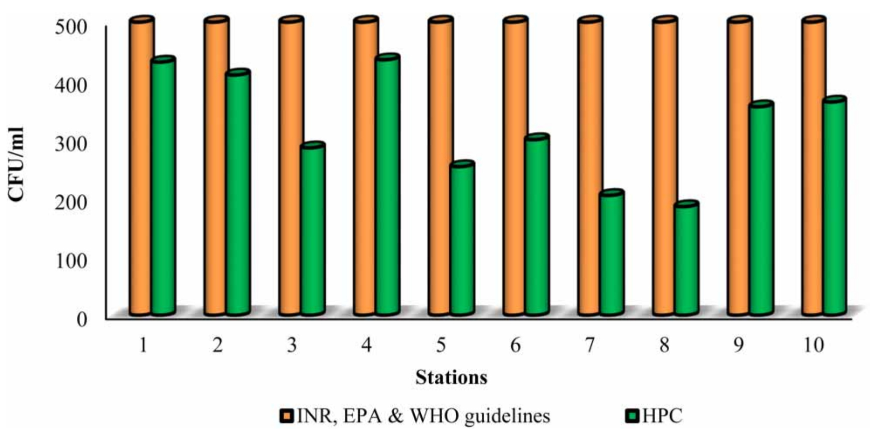

Figure 3 | Mean of the HPC results compared with HPC guidelines for drinking water.

Chloride and sodium together create common table salt. Chloride in water may be considerably increased by treatment processes in which chlorine or chloride is used. High chloride levels cause corrosion and shorten the life of pipes, pumps, hot water heaters and fixtures. Chloride concentration levels in excess of about 250 mg per liter usually produce a noticeable taste in drinking water (Benham *et al.* 2011). All results of chloride measurements met the EPA and INR guidelines. WHO has not set a guideline value for pH, but the EPA and INR have set guideline values of 6.5–8.5 and 6.5–9 for pH in drinking water, respectively. All results of pH measurements met EPA and INR guidelines for drinking water.

Sulfates occur naturally in numerous minerals, including barite ($BaSO_4$), epsomite ($MgSO_4.7H_2O$) and gypsum ($CaSO_4.2H_2O$) (Greenwood & Earnshaw 1984). These dissolved minerals contribute to the mineral content of drinking water. Sulfate minerals can cause scale build-up in water pipes similar to other minerals and may be associated with a bitter taste in water that can have a laxative effect on humans. Uncontrolled observations indicate sulfate in drinking water at concentrations exceeding 500–700 mg/L as a cause of diarrhea (Heizer *et al.* 1997). EPA and WHO have not set a guideline value for EC, but the INR has set a guideline value of 1,500 μS/cm for EC in drinking water, so all results of EC measurements in this study met the INR guidelines. Also, in our study, all results of TDS measurements met EPA, WHO and INR guidelines for drinking water.

As seen in Table 2, the costs of treated water in a distribution system, decentralized municipal desalination plants and bottled water are 13.5 cent/m^3, 13.51 \$/m^3 and 18 cent/lit (180 \$/m^3). Therefore, due to the lower price, many people in different parts of Iran (such as Bushehr) prefer to use treated water from decentralized municipal desalination plants rather than to bottled water. There are different methods for purifying drinking water to provide safe and healthy water for consumers. Today, membrane separation technology has received much attention among consultant engineers, designers of environment pollution control systems, and industrial factory engineers (Ozaki & Li 2002). The membrane processes play an important role in providing high quality, healthy drinking water. Its purpose is to remove minerals, turbidity, synthetic organic materials and disinfection by-products from the water (Hobson *et al.* 2007). They are highly efficient at preventing bacteria and protozoan cysts such as *Cryptosporidium* and *Giardia lamblia* cysts (Wohlsen *et al.* 2004). Thus, the use of water desalination devices has recently received more attention. RO, microfiltration (MF), nanofiltration (NF), and ultrafiltration (UF) are the main membrane processes for the removal of minerals from water (Ozaki & Li 2002). Reverse osmosis is a technology that is used to remove large groups of contaminants such as dissolved salts (ions), particles, colloids organics, bacteria and other microorganisms from water by pushing the water through a semi-permeable membrane under pressure (Fahiminia *et al.* 2014). Considering the increasing use of desalination plants using the RO process across Bushehr, it is necessary to qualitatively control the outlet waters of these devices.

In the collected samples from the outlet waters of these facilities, all parameters were in the range of safe drinking water but 10% of HPC measurment were not in the favorable standard range. In a study by Khodadadi *et al.* (2016) on the chemical, physical and biological quality of exiting water from desalination water facilities in Birjand, Iran, it was found that in all the collected samples from these facilities, TDS, calcium, magnesium, chromium, manganese, and nitrite parameters were in the range of safe drinking water but the total hardness was not in the desirable standard range in 2.7% of samples, which is likely due to the high hardness level of entering water from groundwater resources. In another study by Miranzadeh & Rabbani (2010) on the chemical quality evaluation of inlet and outlet waters taken from desalination plants utilized in Kashan, Iran, it was found that the average concentrations of chemical parameters in treated water were: TDS = 245 mg/L, total hardness = 118 mg/L as $CaCO_3$, nitrate = 2.5 mg/L, fluoride = 0.2 mg/L, sulfate = 24 mg/L, chloride = 63 mg/L and pH range = 6.8–7. In their study, based on the findings on desalinated water, all parameters were in accordance with the optimum concentration levels for drinking water. Their results on pH values were consistent with our results. In contrast to our study, the results of research by Yari *et al.* (2007) on the quality of water extracted from desalination facilities in the cities and villages of Qum, Iran, showed that pH values of exiting water of all facilities were less than the favorable value and reached less than 6, demonstrating that the pH of exiting water of these facilities tended toward acidity and corrosion. In the study by Deghani *et al.* (2013) on the physical, chemical and microbial quality of raw and treated water from desalination plants by reverse osmosis in Qeshm, Iran, it was shown that the total hardness and fluoride in the treated water from this process were lower than desirable limits and chloride concentration was higher than the permitted limit. The rest of the chemical, physical and microbiological parameters in the mentioned study were in acceptable ranges. In the study by Belkacem *et al.* (2007) on the treatment of groundwaters by reverse osmosis in Algeria, it was shown that treatment by the reverse osmosis unit effectively decreased the conductivity and TDS of the groundwater by more than 95% for the totality of constituent ions, and microorganisms were also eliminated. In another study by Shams *et al.* (2012) on the physicochemical qualities of raw and treated water of a decentralized municipal desalination plant water in Gonabad, Iran, the results showed that the TDS value was 868.7 mg/L in the inlet waters, reaching 182.1 mg/L in the outlet waters. The pH values in the inlet and outlet waters were 8.23 and 7.97, respectively. The choloride and sulphate oncentrations were 196.8 and 122.46 mg/L in the inlet waters, and reached 55.09 and 53.04 mg/L in the outlet waters, respectively. Also, total hardness and total alkalinity were 129.5 and 235.2 mg/L as $CaCO_3$ in the inlet waters, and reached 42.01 and 63.91 mg/L as $CaCO_3$ in the outlet waters, respectively. The results of the present study on microbial measurements showed that none of the samples had coliforms contamination, which is in agreement with those of Khodadadi *et al.* (2016); while in similar research on desalination facilities in Qum, 15 samples (6%) had coliform contamination by *Eschershia coli* (Yari *et al.* 2007). Also, in our study, 10% of the HPC bacteria values were outside the accepted range and the mean amount of these bacteria in some samples increased in the outlet waters compared to inlet waters. This can be due to the formation of microbial film on the membranes. In a study by Schwartz *et al.* (2003) on biofilm formation on membranes, it was found that HPC bacteria were resistant to antibiotics and resistant genes were separated. In Payment *et al.*'s (1991) research, it was shown that domestic reverse osmosis filtration units were contaminated with HPC bacteria at a higher value than 500 CFU/mL.

CONCLUSIONS

In the present study, the role of decentralized municipal desalination plants in the removal of physical, chemical and microbial parameters from drinking water in Bushehr, Iran, were evaluated and compared with national and international guidelines for drinking water. The results demonstrated that mean concentration levels of all parameters examined in the outlet drinking water taken from the decentralized municipal desalination plants in Bushehr generally complied with the current drinking water guidelines based on their bacterial and physiochemical properties. However, 10% of HPC samples did not comply with the INR, EPA and WHO drinking water guidelines. The results showed that decentralized municipal desalination plants by RO process could remove most parameters from inlet waters and these devices have high efficiency for providing healthy drinking water based on qualitative guidelines.

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