Research Paper

Chemical and microbiological quality of desalinated waters in Birjand city, Iran

Ali Naghizadeh, Mohammad Kamranifar, Fatemehsadat Masoudi and Mohammad Reza Nabavian

ABSTRACT

The importance of water in everyday life is clear for humans and living creatures. In addition to supplying the water required for the body, it also contains necessary minerals. An increase or decrease in these minerals is responsible for various diseases and problems. Due to the growing consumption of treated water in Birjand, Iran and the need for the continuous monitoring of the quality of treated water, this descriptive research aimed to determine the chemical and microbiological quality of treated water of desalination stations in Birjand from September 23rd, 2015 to March 19th, 2016 (autumn and winter). Samples were directly taken from the desalination stations of Birjand. Physical and chemical tests were performed according to the Standard Methods. The results were compared with national standards as well as World Health Organization (WHO) guidelines. The results showed that almost all measured chemical and bacterial characteristics were less than the national and international standards. Also, the samples were standard in terms of coliforms and fecal coliforms. In some stations the concentrations of free residual chlorine and also magnesium were higher than standards. Therefore, periodic investigation of quality parameters is recommended in all desalination stations to reflect the results to authorities.

Key words | Birjand, chemical quality, desalination, Iran, microbiological quality

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INTRODUCTION

The importance of water in everyday life is clear for humans and living creatures. Optimal quality and quantity of water is essential for human survival (Mousazadeh 2013; Derakhshani *et al.* 2017). In addition to supplying the water required for the body, it should contain minerals necessary for the body (Yari *et al.* 2007). Therefore, drinking water quality can play a key role in human health.

Drinking water, in addition to being apparently transparent, clear and free from turbidity, must also maintain optimal chemical and microbiological levels (Miranzadeh & Rabbani 2010). The presence of certain bacteria such as *Escherichia coli* and coliforms bacteria in water shows defects in the water treatment process and it may have been polluted with human and animal feces. In terms of the chemical quality of drinking water, polyvalent cations, particularly calcium and magnesium, can cause hardness of water. In domestic settings, hard water is often indicated by a lack of foam formation when soap is agitated in water, and by the formation of lime scale in kettles and water heaters (Al-Khatib & Arafat 2009; Tavangar *et al.* 2014). According to World Health Organization (WHO) guidelines and Iranian National Standards, maximum total hardness is 500 mg/L

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as $CaCO_3$ (ISIRI 2009; WHO 2011). Higher concentrations of dissolved solids cause salty water and decreases the tendency of consumers (Miranzadeh & Rabbani 2010). WHO published the first guidelines for drinking water quality in 1984 and 1985 and revised and forwarded to countries in 1993, 2003, and 2011 (Dehghani *et al.* 2013b). In Iran, the first document for chemical and physical quality for drinking water was developed in 1966, known as Standard 1053. It was reviewed and republished in 2009 (ISIRI 2009).

Today, desalination plays a key role in supplying water in different countries. The role is increasingly highlighted due to the increase in water consumption and decrease in natural and renewable fresh water resources (Sadigh *et al.* 2015). Various desalination methods have been developed including Multi-Stage Flash Distillation (MSF), Multi Effect Distillation (MED), Vapor Compression Distillation (VCD), and desalination processes working with membranes, such as Electro-Dialysis (ED), Reverse Osmosis (RO) and Nano-Filtration (NF) (Li & Wang 2010). So far, more than 15,000 desalination projects have been installed worldwide. Almost 50% of these desalination projects have RO processes. RO has experienced a dramatic increase due to its simplicity and relatively low cost (Schiffler 2004; Khawaji *et al.* 2008; Li & Wang 2010). In general, there are two types of desalination devices: thermal process-based and membrane process-based. However, there are other types of desalination processes working with both thermal and membrane (hybrid) processes. The hybrid desalination processes are used less than the other main processes (Mezher *et al.* 2011). Worldwide, RO membrane processes account for about 80%, and thermal processes account for 20%, of desalination units (Greenlee *et al.* 2009).

Membrane processes work by preventing or limiting the passage of ions through special salt. RO is a widely used important commercial membrane process (Raluy *et al.* 2006). In the RO process, salty water is pumped into a closed chamber which is under pressure against a membrane. Pure water penetrates the membrane due to the pressure difference, while the salty water is drained from the back of the system. The operational pressure required for sea water treatment is usually 55–68 bars. This amount is lower for brackish water (Fritzmann *et al.* 2007).

In recent years, some studies have been conducted on water quality from desalination devices in some parts of Iran. They were mainly based on RO. Yari *et al.* (2007) conducted a study in Qom, Iran on the chemical, physical, and microbiological quality of treated water from RO-based desalination stations. Dehghani *et al.* (2013a) investigated the quality of input and output water of desalination devices of Qeshm Island, Iran. Schoeman & Steyn (2003) investigated the removal of nitrates in a rural region of South Africa using RO. Their study showed that RO was very effective in the removal of nitrogen in rural areas. The results showed that RO was capable of reducing nitrate concentrations from 42 to 1 mg/L (98% reduction).

Birjand Plain is located in the eastern part of the Iranian central desert. It is a very poor area in terms of surface water. Therefore, major pressure is on water withdrawals from aquifers and ground water for industrial and agricultural sectors. At present, water is supplied in the region through groundwater. In terms of chemical quality, this water is faced with increasing TDS. The results of the study by Rajaei *et al.* (2012) showed excessive chloride in 25% of the wells in Birjand and Qaen, Iran. Chloride varied between 21.9 and 715 mg/L, the average being 286 mg/L, showing the presence of gypsum and salt geological formations in the region. The results of their study showed that the residual average of dry solids and EC were 1,259 and 2,024 mg/L, respectively. Twenty-five per cent of the wells had hardness above the national standard (Rajaei *et al.* 2012).

Consumers are not willing to use the water due to the salt and hardness of Birjand drinking water. As a result, water desalination stations have gained popularity. Due to the importance of drinking water quality of desalination stations, this paper aimed to investigate the chemical and microbiological quality of output water from desalination stations of Birjand city in autumn and winter, 2015.

MATERIALS AND METHODS

The present work is a cross-sectional study in 2015 on some desalinations of Birjand city in Iran. The location of Birjand city in Iran is shown in Figure 1. Water samples were taken on different days due to the duration of the project (autumn and winter). Moment Sampling was employed to collect the water from the taps, then the water was transferred to

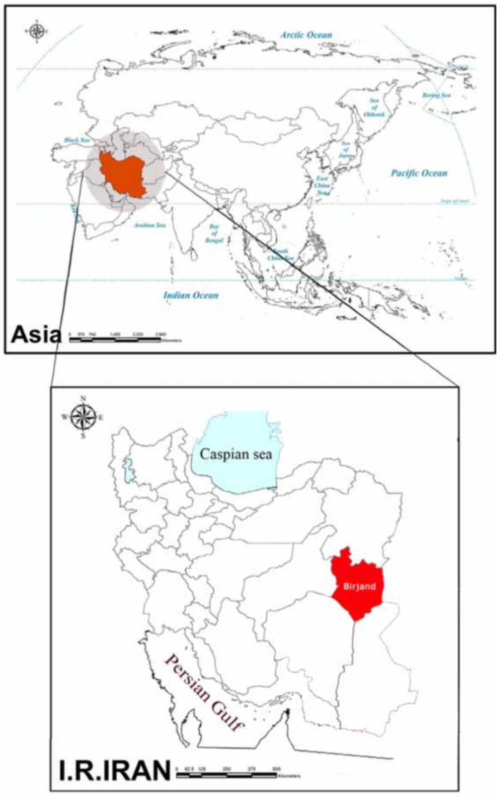


Figure 1 | The position of Birjand region, Iran.

the laboratory. One liter PET containers were used for the physical and chemical tests. Sterile glass jars were used for microbiological tests according to the instructions in Standard Methods. In microbiological tests, total coliforms and fecal coliform indices were applied using a multiple tube fermentation (MTF) technique. The chemical parameters were total hardness, calcium, magnesium, pH, alkalinity, sulphate, and free residual chlorine using the Standard Method Book. All tests were performed in the Environmental Health Engineering Laboratory of Birjand University of Medical Sciences. The data were analyzed in Excel 2007. Then, the data were compared with those of the WHO guidelines and Institute of Standards and Industrial Research of Iran. Tables 1 and 2 show these data.

RESULTS AND DISCUSSION

In this study, the microbiological and chemical characteristics of 10 desalination stations were investigated in Birjand, Iran in autumn and winter, 2015. The treated water of the desalination stations was coded from TW1 to TW10. According to Figure 2, showing the total hardness of water samples, the highest values of hardness were 200 and 360 mg/L as $CaCO_3$ in autumn and winter, respectively. Both values were lower than the Iranian national standards and WHO guidelines.

As can be seen in Figure 2, the total hardness of desalinated water was 40–360 mg/L as $CaCO_3$. It was lower than

Table 1 | Physico-chemical characteristics of drinking water (ISIRI 2009; WHO 2011)

Parameters	Unit	Admissible limit in Iranian standards	Maximum contaminant level in Iranian standards	WHO guidelines
Total hardness	mg/L as $CaCO_3$	200	500	500
Calcium	mg/L	300	–	–
Magnesium	mg/L	30	–	–
pH	–	6.5–8.5	6.5–9	6.5–8.5
Bicarbonate	mg/L	–	–	150
Sulphate	mg/L	250	400	250–500
Alkalinity	mg/L	–	–	–
Residual free chlorine	mg/L	–	0.5–1	–

Table 2 | Microbiological characteristics of drinking water (ISIRI 2007; WHO 2011)

Microbiological parameters	Unit	Admissible limit in Iranian standards	WHO guidelines
Fecal coliforms	MPN/100 mL	Negative	Negative
Total coliforms	MPN/100 mL	Negative	Negative

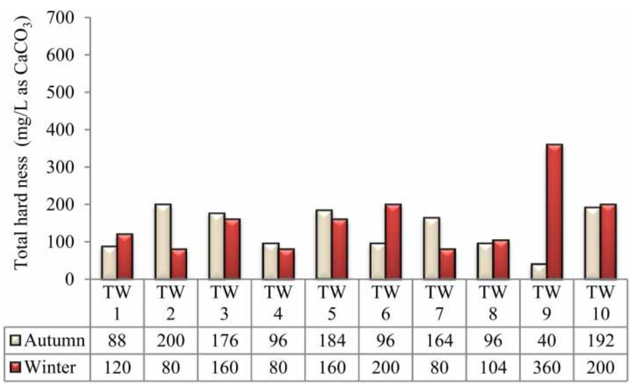


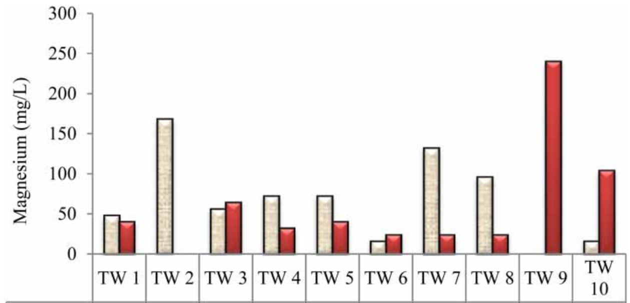
Figure 2 | Total hardness of desalination water in autumn and winter.

the maximum contaminant level in all samples. The results of the study by Miranzadeh & Rabbani (2010) on desalinations of Kashan, Iran were similar to the present research. Hardness is effective on taste and odor of the drinking water. Very low amounts of hardness can contribute to pipe erosion. High hardness is responsible for the formation of shell in boilers and thermal processes in industry (Pindi *et al.* 2013). Note that according to the studies on the relationship between the reduced incidence of cardiovascular disease and water hardness, long-term water consumption with low hardness not only helps health but also is harmful, endangering the health of individuals in the long run so that the reduced calcium, magnesium, and minerals intake increases the prevalence of bone disease such as osteoporosis and lack of nutrients (Guilbaud *et al.* 2012).

As shown in Figure 3, the concentration of calcium was lower than the maximum values of Iranian national standards in all cases. Calcium was 0–176 and 48–176 mg/L in autumn and winter, respectively.

According to Figure 4, the magnesium concentration was 0–168 and 0–240 mg/L in autumn and winter, respectively. The results showed that all water samples had magnesium concentrations above the Iranian admissible limit (30 mg/L) except for TW6, TW9, and TW10 desalinations. In winter, the magnesium concentration of TW1, TW3, TW4, TW5, TW9, and TW10 in the desalination stations exceeded the permissible limit.

The study performed by Tavangar *et al.* (2014) on desalination stations in Bojnurd, Iran showed that calcium was lower than the admissible limit in all samples and magnesium was greater than the Iranian standards. Calcium and magnesium originates in rocks, however, magnesium was lower than calcium, which is associated with a lower amount of magnesium in the Earth's crust. Higher concentrations of magnesium in water can result in an unpleasant flavor (Nkamare *et al.* 2012). Magnesium has a laxative effect, damaging thermal installations and water transfer pipes. As a result, it contributes to high costs for treatment and water heating installations (Heidari *et al.* 2010). Calcium is also believed to be an essential element for the nervous system and bone formation (Nkamare *et al.* 2012).

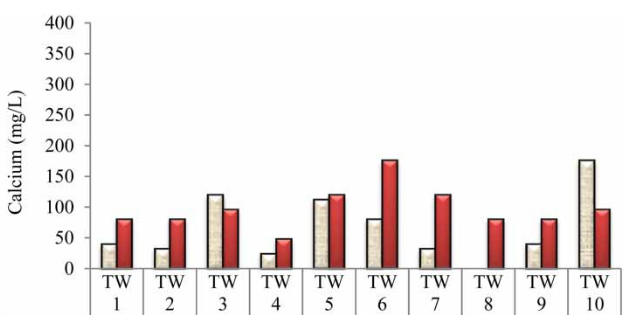


	TW 1	TW 2	TW 3	TW 4	TW 5	TW 6	TW 7	TW 8	TW 9	TW 10
Autumn	48	168	56	72	72	16	132	96	0	16
Winter	40	0	64	32	40	24	24	24	240	104

Figure 4 | Concentration of magnesium of water samples in autumn and winter.

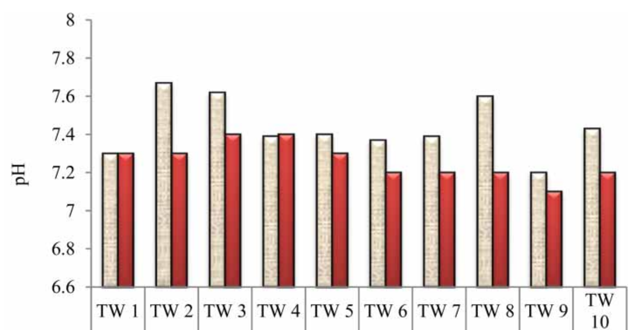
Figure 5 shows the results of the pH investigation. The results showed that pH was in the range of 7.2–7.67 in autumn and 7.1–7.3 in winter. A comparison with the Iranian national standards and WHO guidelines showed that pH was not above the standards.

According to the guidelines of the Iranian Institute of Standards and Industrial Research, the permissible limit and the maximum permissible limit of pH in drinking water is 7–8.5



	TW 1	TW 2	TW 3	TW 4	TW 5	TW 6	TW 7	TW 8	TW 9	TW 10
Autumn	40	32	120	24	112	80	32	0	40	176
Winter	80	80	96	48	120	176	120	80	80	96

Figure 3 | Concentration of calcium of water samples in autumn and winter.



	TW 1	TW 2	TW 3	TW 4	TW 5	TW 6	TW 7	TW 8	TW 9	TW 10
Autumn	7.3	7.67	7.62	7.39	7.4	7.37	7.39	7.6	7.2	7.43
Winter	7.3	7.3	7.4	7.4	7.3	7.2	7.2	7.2	7.1	7.2

Figure 5 | pH of water samples of desalinations in autumn and winter.

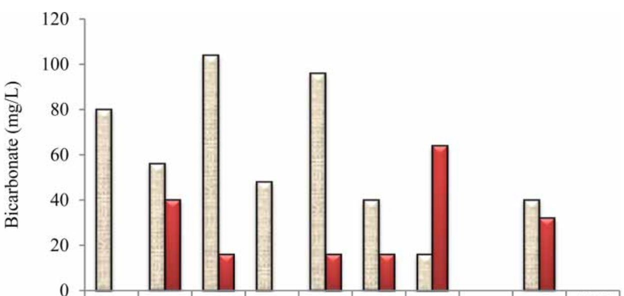
and 6.5–9, respectively. In the WHO guidelines, the optimal pH is determined to be in the range of 6.5–8.5 (ISIRI 2009; WHO 2011). Based on the investigation in this article and also Figure 5, the pH of desalinated water was lower than the national and WHO guidelines in autumn and winter, respectively, which is consistent with the results of the study conducted by Dehghani *et al.* (2013a) and Belkacem *et al.* (2007).

As seen in Figure 6, the maximum bicarbonate concentration was in autumn and winter, being 104 and 64 mg/L, respectively. In the Iranian national standards, no optimal level or limit was mentioned for bicarbonate. However, it is 150 mg/L in the WHO guidelines. According to Figure 6, bicarbonate was low in all samples.

The results of sulphate concentration in Figure 7 show that it was lower than the permissible limit in all desalination stations. Maximum and minimum sulphate concentrations were 14.57 and 0.57 mg/L in autumn and 41.86 and 15.86 mg/L in winter, respectively. They were far lower than the Iranian national standards and WHO guidelines.

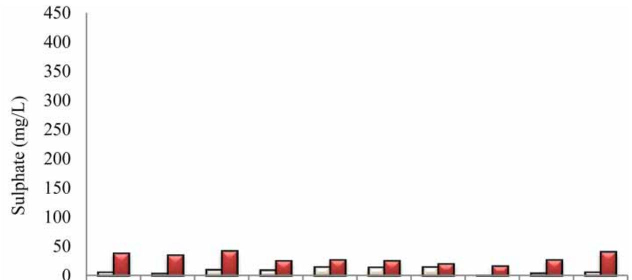
The results of the present study are consistent with those performed by Yari *et al.* (2007). Sulphate is a toxic anion of water. Excessive use of sulphate results in adverse physiological effects such as dehydration and gastrointestinal irritation (Saleh *et al.* 2001). High levels of sulphates can be laxative for those who are accustomed to the water. Sulphates can also contribute to hardness and foam in boilers (Molaei Tvani *et al.* 2016).

Alkalinity was another parameter studied in this research and the results are shown in Figure 8. Alkalinity was 20–160 mg/L in autumn and 40–95 mg/L in winter.



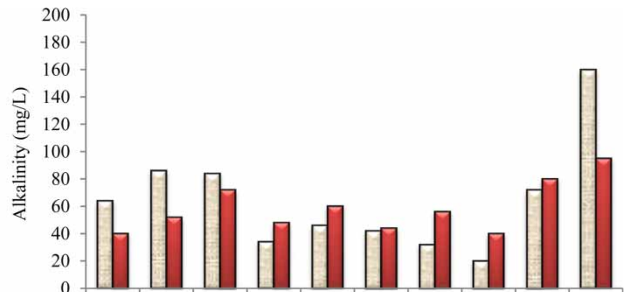
	TW 1	TW 2	TW 3	TW 4	TW 5	TW 6	TW 7	TW 8	TW 9	TW 10
Autumn	80	56	104	48	96	40	16	0	40	0
Winter	0	40	16	0	16	16	64	0	32	0

Figure 6 | Bicarbonate concentration of water samples of desalinations in autumn and winter.



	TW 1	TW 2	TW 3	TW 4	TW 5	TW 6	TW 7	TW 8	TW 9	TW 10
Autumn	5.86	3.43	9.71	9	14.57	14	14.43	0.57	3.86	5.57
Winter	37.57	34.71	41.86	25.14	26.86	24.86	19.86	15.86	26.71	40.43

Figure 7 | Sulphate concentration of water samples of desalinations in autumn and winter.



	TW 1	TW 2	TW 3	TW 4	TW 5	TW 6	TW 7	TW 8	TW 9	TW 10
Autumn	64	86	84	34	46	42	32	20	72	160
Winter	40	52	72	48	60	44	56	40	80	95

Figure 8 | Alkalinity of water samples of desalinations in autumn and winter.

No standards have been defined for alkalinity by the WHO guidelines and national standards. Maximum alkalinity was reported to be 160 and 95 mg/L in the autumn and winter, respectively (Figure 8). Alkalinity is not of much importance in terms of health; however, high alkalinity is not pleasant (Tavangar *et al.* 2014).

Figure 9 shows the residual free chlorine of the treated water from the desalination station. The results showed that it was lower than the maximum contaminant level in all samples.

According to the Institute of Standards and Industrial Research of Iran, 0.5–1 mg/L of free residual chlorine is required to prevent secondary contamination. According to Figure 9, free residual chlorine was lower than the maximum contaminant level in all water samples which increased the likelihood of secondary contamination. As the increase in the operation period of the desalination

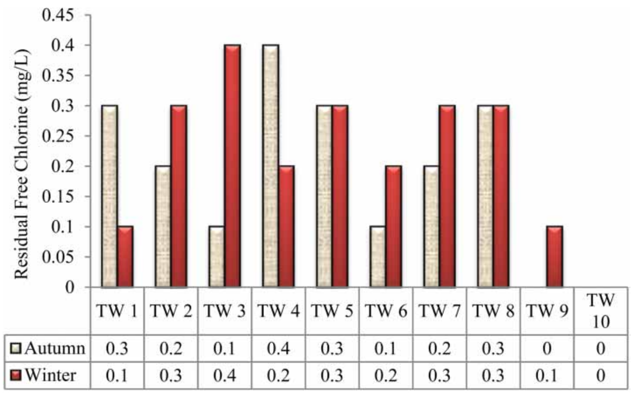


Figure 9 | Residual free chlorine of water samples of desalinations in autumn and winter.

Table 3 | Results of microbiological quality test of 10 desalinations

		Total coliform		Fecal coliform	
Number of stations	**Season**	**Negative**	**Positive**	**Negative**	**Positive**
10	Autumn	10	0	10	0
	Winter	10	0	10	0

devices is responsible for the increase in the concentration of various combinations of bacteria at layer and filter beds, they can act as nutrients, preparing the ground for bacteria growth inside filters (Liikanen *et al.* 2006).

Table 3 shows the microbiological analysis of the samples. Total coliform and fecal coliform were negative in 100% of samples and no microbiological contamination was observed.

Microbiological contamination is one of the important quality parameters of water. Pathogenic microorganisms in drinking water can threaten the health of consumers. They can develop diseases such as typhoid, cholera, hepatitis, and diarrhea (Dehghani *et al.* 2013b). In this article, two microbiological parameters (total coliform and fecal coliform) were analyzed. No microbiological contamination was found in this regard, showing good microbial quality of the drinking water (Table 3).

CONCLUSIONS

Desalination reduces minerals and improves the taste and odor of drinking water. However, a decrease or increase in some of these minerals contributes to various diseases. They must be at optimal levels to maintain the health of consumers. This article aimed to investigate the physical, chemical, and microbiological quality of output water of desalination. All parameters were at optimal levels except for free residual chlorine and magnesium concentration in certain samples.

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