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Evaluation of Point-of-Use Drinking Water Treatment Systems Efficiency in Reducing or Removing Physicochemical Parameters and Heavy Metals

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ABSTRACT

Introduction: Nowadays, many people have bought and installed home water treatment devices (point-of-use drinking water treatment systems), as an essential measure, to improve their health.

Materials and Methods: This cross-sectional study was conducted to evaluate the parameters of drinking water of Rafsanjan city and home water treatment device in summer 2017. Water samples at the inlet and outlet of the device with 15 day intervals for three months (approximately 48 samples, summer) were collected. Then, the concentration of heavy metals, total hardness, EC, sodium and nitrate were measured in inlet and outlet of treatment devices. All data were statistically analyzed by SPSS software version 18.

Results: The results showed that in the inlet water, the EC and pH values were in the standard ranges. The concentrations of arsenic was higher than the permissible limits and other parameters including total hardness, calcium, sodium, magnesium, nitrate, copper, zinc and lead were lower than the standard limits. The highest reduction efficiency was obtained for copper, zinc and arsenic respectively, and the lowest reduction efficiency was reported for nitrate and calcium.

Conclusion: Therefore, it can be concluded the devices could reduce the concentrations of the parameters under the standard limits. Due to the relationship between heart disease and light water, it is suggested that, in view of the high arsenic content in Rafsanjan water, filters at the inlet municipal water can be used to absorb heavy metals, especially arsenic.

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Introduction

Drinking water is defined as water with physicochemical and biological parameters in standards ranges which its short- or long-term use will not have any complication for human beings [1]. In addition to being transparent, clear and free from turbidity, it should also have permissible chemical and microbial quality [2]. Contamination of water is divided into three types, bacteria and viruses, toxic chemicals and heavy metals [1]. Today, in addition to microbial contamination, chemical contamination is one of the important issues in water health. In this regard, heavy metals are of particular importance [3]. Human activities that mainly lead to the accumulation of heavy metals in the environment include extraction of metals, agricultural fertilizers, electronic industries, batteries and industrial sewages [4]. Heavy metals do not degrade in the environment and can accumulate in the body during the time [5, 6]. The contamination of drinking water sources by arsenic has put the health of millions of people across the globe into danger [7]. Cadmium is a non-essential element for the living organism and can have toxic effects by replacing with zinc. Small amounts of cadmium can cause kidney damage and in some cases human cancers [8]. High concentrations of Copper could have toxic effects for some living organisms which can result in respiration problems and the effect on cell wall of microorganism [8]. Zinc is known as an essential micronutrient for humans, plants and animals; however, the exposure to excess amounts of metals can cause certain damages in human, such as metabolism impair and increased oxidative stress. Therefore, it is important to identify heavy metals in water samples [9]. In addition to heavy metals, nitrate can affect the on water quality. The presence of nitrate in agricultural fertilizers and its entry into the soil can influence on surface and groundwater. Nitrate can enter the body then; convert to nitrite in the blood stream and change iron II into iron III. Hemoglobin is converted to methemoglobinemia, which cannot transport oxygen, and develop hypoxia in tissues [10]. Nitrate in water can also be converted to nitrite and produce the carcinogenic compounds nitrosamide [11]. The low chemical quality of water is responsible of cardiovascular diseases, gastrointestinal disorders, renal failure, and hypertension[12]. Multivalent calcium and magnesium cations at various concentrations are often present in water. According to the national standards of Iran (No. 1053) [13], the maximum permissible total hardness is 500 mg (calcium carbonate). High levels of total dissolved solids (TDS) also cause water salinity, and thus reduce the willingness of consumers to use the water [14].

Nowadays, many people have bought and installed home water treatment devices (point-of-use drinking water treatment systems), as an essential measure, to improve their health and this device is being increasingly used. However, inadequate quality of the water at the outlet of these devices can be a threat to health, especially in vulnerable people [4]. The aim of this study was to measure the qualitative parameters, heavy metals (arsenic and lead, copper and zinc) in the water samples at the inlet and outlet of home water treatment devices in Rafsanjan City.

Materials and Methods

This cross-sectional descriptive study was conducted to evaluate the physicochemical parameters of water at the inlet and outlet of domestic point-of-use treatment systems used in Rafsanjan in 2017. The samples were gathered in three months (summer). After selecting two brands of point-of-use systems, four households using the two brands were identified. By considering that water of Rafsanjan is supplied from two different resources of Bardsir and Rafsanjan, therefore, four families which used the same resource were chosen. In this study, two brands of home water treatment devices with reverse osmosis were studied. To reduce the differences, a new filter was installed for each household, and the domestic water meter was recorded at each sampling. Water at the inlet and outlet of the device was sampled at 15 day intervals for three months (summer) in six steps. A total of 48 samples were collected.

Preparation of samples

Sampling were prepared according to Iran National Standard Procedures (No 2347) and then stored in polyethylene containers with labeling contained date, hour, and place of sampling and water temperature [15]. Electrical conductivity (EC) and pH were determined at the point of sampling. The containers were immediately transferred to the laboratory for measurement of the parameters like total hardness, calcium, magnesium and sodium, as well as nitrate and heavy metals (arsenic, lead, zinc and copper).

Heavy metals concentration Measurement

The levels of arsenic, lead, zinc and copper were measured by atomic absorption spectrometry according to a standard procedure by using the graphite furnace (SavantAA, GBS, Australia) [16, 17].

Total hardness measurement

The total hardness was measured by titration using Ethylene Diamine Tetra Acetic Acid (EDTA) according to the standard procedure (No. 2356) of the Institute of Standards & Industrial Research of Iran [18].

Calcium hardness measurement

Calcium hardness was measured by the standard procedure (No. 2356) of the Institute of Standards and Industrial Research of Iran [18].

Magnesium hardness measurement

The magnesium hardness was measured by calculating the difference between total hardness and calcium hardness.

EC measurement

The EC was measured according to the standard (No. 2351) of the Institute of Standards & Industrial Research of Iran [19] using a conductivity meter (Hanna HI9033 EC).

Sodium measurement

Sodium test was performed by using a photoelectric flame photometer according to the standard procedure (No. 1053) [13].

Nitrate measurement

Nitrate level was measured by a spectrophotometer (Hach, DR2000) [20]. First, water samples were filtered with a filter paper. Ten ml of each samples were transferred into the flask (a control sample was also used). Then, the reagents (Hach, USA) were added to the samples according to the instructions, and the resulting mixtures were stirred for 1 min and then left for 5 min. The nitrate concentration of samples was calculated by spectrophotometer.

Statistical analysis

All data were statistically analyzed by SPSS software version 18. The t-test was used to compare mean values and $p < 0.05$ was considered significance. Finally, the average concentrations of parameters were compared to the standards of Iran [16].

Ethical issues

This study was conducted with the approval of Shahid Sadoughi University of Medical Sciences and Health Services, Medical Ethics Committee. Code: IR.SSU.SPH.REC.1396.118

Results

Determination and comparison of parameters in two water sources of Rafsanjan

The average concentrations of physicochemical parameters and metals in the inlet water samples from the two water sources, Rafsanjan-Bardsir and Bardsir, are shown in Table 1. The results showed that there was no significant difference in the physicochemical parameters and heavy metals between the two water sources.

Table 1: Mean values of qualitative and chemical parameters in two water sources of Rafsanjan

Parameters		Rafsanjan-Bardsir (Mean ± SD)	Bardsir (Mean ± SD)
EC (µmoh/cm)		746.89 ± 56.9^{a}	658.73 ± 154.785^{a}
pH		8.04 ± 0.23^{a}	7.91 ± 0.06^{a}
Hardness (mg/l)	Total	139.44 ± 5.69^{a}	131.33 ± 16.85^{a}
	Calcium	44.66 ± 5.73^{a}	57 ± 19.63^{a}
	Magnesium	94.94 ± 7.30^{a}	71.33 ± 18.14^{a}
Sodium (mg/l)		5.44 ± 0.73^{a}	5.88 ± 1.33^{a}
Nitrate (mg/l)		8.69 ± 0.33^{a}	8.56 ± 0.54^{a}
Cu (ppb)		ND^{*a}	2.80 ± 0.80^{a}
Zn (ppb)		49.70 ± 5.40^{a}	37.40 ± 7.90^{a}
Pb (ppb)		4.10 ± 0.70^{a}	4.45 ± 0.580^{a}
As (ppb)		69.61 ± 8.70^{a}	73.20 ± 12.00^{a}

* ND: not detected in studied samples.

LOD: 2-100 ppb

Different letters in each row show significant differences ($p < 0.05$).

Determination and comparison parameters at the inlet and outlet water of the home water treatment devices

In Table 2, the comparison of qualitative parameters (pH, EC, sodium, nitrate, total hardness, calcium and magnesium), and heavy metals concentrations (arsenic, lead, zinc and copper) between the water samples at the inlet and outlet of the devices was shown. As it is shown the EC and pH values of the inlet water are in standard range. The arsenic concentrations was higher than the maximum allowable limits and other parameters including total hardness, calcium, magnesium, sodium, nitrate, copper, zinc and lead were lower than standard limits. The concentrations of qualitative parameters in the water samples at the inlet and outlet of the treatment devices indicates that the concentrations of these parameters decreased after using the home water treatment device, significantly.

Table 2: The mean values of chemical and qualitative parameters in the water at the inlet and outlet of home water treatment devices

Parameters		Inlet water (Mean ± SD)	Outlet water (Mean ± SD)	Iran optimum standard	Iran standard limits
EC (µmoh/cm)		863.42 ± 56.30^{a}	138.57 ± 22.25^{b}	-	< 400
pH		8.03 ± 0.22^{a}	7.13 ± 0.37^{b}	7-8.5	6.5-9.2
Hardness (mg/l)	Total	161.37 ± 5.18^{a}	23.95 ± 3.28^{b}	150	500
	Calcium	61.00 ± 5.7^{a}	13.25 ± 2.89^{b}	75	200
	Magnesium	101.87 ± 7.65^{a}	12.83 ± 2.41^{b}	50	150
Sodium (mg/l)		6.71 ± 0.73^{a}	1.16 ± 0.17^{b}	-	200
Nitrate (mg/l)		14.93 ± 0.14^{a}	6.27 ± 0.19^{b}	-	45
Cu (ppb)		0.66 ± 0.62^{a}	ND^{*b}	50	1500
Zn (ppb)		54.12 ± 4.73^{a}	7.47 ± 0.99^{b}	5000	15000
Pb (ppb)		4.18 ± 0.57^{a}	ND^{*b}	-	100
As (ppb)		81.34 ± 7.54^{a}	10.87 ± 2.27^{b}	-	50

* ND: not detected in studied samples.

LOD: 2-100 ppb

Different letters in each row show significant differences between inlet and outlet water ($p < 0.05$).

The Mean concentration of all parameters except for arsenic was significant in comparison to standard limits ($p < 0.05$).

The efficiency of the home water treatment devices

Table 3 shows the minimum and maximum efficiency of the two brands of home water treatment devices to remove studied parameters. The highest removal efficiency was obtained for the parameters copper, lead, zinc and arsenic for brand 1 and for copper, lead, zinc and magnesium for brand 2. Overall, it can be concluded that brand 2 with a mean removal efficiency of 31.77% was more efficient than brand 1, although this difference was not statistically significant.

Table 3: Efficiency of two brands of home water treatment device

Parameters	**Minimum Efficiency (%)**		**Maximum Efficiency (%)**		**Mean Efficiency (%)**	
	Brand 1	**Brand 2**	**Brand 1**	**Brand 2**	**Brand 1**	**Brand 2**
Ec	45	5	98	92	80.40	80
Total hardness	60	72	94	92	83	86
Calcium	43	50	96	96	76	72
Magnesium	60	64	97	96	84	87
Sodium	41	60	98	98	80	84
Nitrate	42	52	70	68	56	58
Cu	99	99	99	99	99	99
Zn	64	72	99	99	84	86
Pb	99	99	99	99	99	99
As	60	66	99	99	88	85

Discussion

Due to the lack of selective removal system in the water treatment devices, all cations and anions are eliminated regardless of their usefulness or harm [21], therefore the balance of minerals in the outlet water can be disturbed and put the consumer health into danger. In recent years, reverse osmosis has been very frequently applied in water treatment systems, which is known as a 21st century technology [22].

The consumers have been encouraged to use reverse osmosis due to its easy installation in home to achieve optimal water quality. The results of this study showed that, except for arsenic, the levels of the parameters in the inlet water of Rafsanjan were lower than the Iran National Standards of drinking water. The home water treatment device significantly was reduced all physicochemical parameters in the outlet water in the standard range. The EC of water represents its dissolved anions and cations, which their increase can have direct effect on water salinity. According to the European Standards, the minimum EC, for drinking water ranges from 400 µmoh/cm to 1000 µmoh/cm. Our results showed that the removal efficiency of the device for the EC was 83.95%, and its average amount in the water samples at the outlet of the treatment devices was obtained 138.5 µmoh/cm. The low level of EC in the present study is attributed to the reduction of water ions in the reverse osmosis treatment process.

The result of research carried out during 2003, on the water treatment systems in Qom, reported the EC of water treated by devices 83-588 µmoh/cm; and the EC was less than 400 µmoh/cm in 83% of the samples [23]. In a study in Shadegan on 12 home and industrial water treatment devices, the EC was reported 140-1990 µmoh/cm [24]. Tavangar et al., showed the average EC of inlet and outlet water of home water treatment system 911 µmoh/cm and 229 µmoh/cm, respectively, with a removal efficiency of 75% [24].

In the present study, the pH of the water was reduced about 0.9%, which was statistically significant when compared to the pH of inlet water. The mean efficiency of pH in brand 1 and brand 2 were estimated 10.30 and 12.5, respectively. The reason for the decrease in pH can be due to high reduction of anions and cations in the reverse osmosis process. In the water samples of the home water treatment devices in Shadegan, pH was ranged from 6.8 to 7.5 [25]. In a study conducted on water treatment devices in Qom, the pH of the outlet water was reported from 5.53 to 6.89 [23]. In the outlet water of treatment devices in Kashan city, the pH was found to decrease slightly and reach a range of 6.8-6.9 [2]. Tavangar et al. indicated the pH of the inlet water of the treatment devices decreased from 8.21 to 7.68 [24]. The mentioned studies confirm the results of the current study. Low hardness is not suitable for drinking, although it is very suitable for industrial uses, so the level of hardness in the outlet water of treatment devices should be above 100 mg/l and range between 100 to 150 mg/l [21]. The results of current study showed that the removal efficiency of point-of-use drinking water treatment systems for total hardness, calcium and magnesium hardness were obtained 84.5%, 74% and 85.5%, respectively. In addition, the results showed that the total hardness, calcium and magnesium hardness of Rafsanjan water were 161.37, 61, and 101.8mg/l, respectively. The mean total hardness, calcium and magnesium hardness at the outlet of home water treatment devices reported 23.95, 13.28 and 12.83 mg/l, respectively. The drinking water of Rafsanjan, according to the WHO classification, is considered as hard water (150-300 mg/l) [26], but after treatment by the point-of-use drinking water treatment, it could be classified as soft water (0-75mg/l). In a study conducted in Bojnourd city, the average total hardness at the inlet and outlet were measured at 568 mg/l and 136 mg/l, respectively, and the total hardness removal efficiency was reported 76% [24]. In a similar study in Kashan, the average total hardness at the inlet and outlet of water treatment devices were approximately 319.37 mg/l and 118.25 mg/l, respectively, with the total hardness removal efficiency of 62.9% [24]. In another study in Qeshm city, the total hardness removal efficiency of water treatment systems was measured 99.5% [22]. The results of these studies are consistent with the present study. In current study, the average sodium removal efficiency of the studied devices was obtained 83.6%. The average sodium concentration at the outlet of the water treatment device decreased significantly, indicating the high sodium removal efficiency of the devices. Sadigh et al. reported that the sodium removal efficiency of the device was 95.05%, which is consistent with the present study [21]. By considering the fact that sodium concentration of water (without treatment) was lower than the Iran national standard, home water treatment devices could reduce it to very low concentrations. Sodium and potassium are among the salts that are important for the taste of water. From the health point of view, the reduction of these two elements can be beneficial for renal and dialysis patients, but it is undesirable for other people due to changes in taste of water [27].

To reduce nitrate from drinking water, various physicochemical and biological processes are used to remove it from drinking water. One of the most practical physicochemical processes to remove nitrate is reverse osmosis. As shown in Table 3, the average nitrate removal efficiency for brands 1 and 2 was obtained 56% and 58%, respectively. Besides that, the average concentration of nitrate in the inlet and outlet water treatment devices was lower than the Iran national standard and the WHO standard (45 mg/l) [26, 27]. Therefore, it can be concluded that domestic water treatment systems have good nitrate removal efficiencies. It is known that nitrate has numerous health effects and is suspected to be carcinogen; the use of these devices can be very useful to prevent the potential effects of nitrates, such as methemoglobinemia and nitrosamine [28]. Naimi et al. found that the average nitrate concentration in the inlet and outlet water of the devices was 5.36 mg/l and 1.85 mg/l, respectively, with a removal efficiency of 65.5% [24]. Sadigh et al. reported mean nitrate levels in the inlet and outlet water of treatment devices were 6.01 mg/l and 0.93 mg/l, respectively by removal efficiency of 79.16% [21]. Dehghani in Qeshm and Sehn in Finland reported the nitrate removal efficiency 92.22% and 91.75%, respectively, which is consistent with the results of our study [22, 29]. According to the US Environmental Protection Agency, the permissible limit of arsenic is 5-10 μg/l [30]. In the guidelines of the WHO and the Iran national standard, the maximum permissible level of arsenic in drinking water is determined 10 and

50 µg/l, respectively [30]. There are several methods for water treatment systems that can reduce arsenic levels of drinking water to the permissible level set by the standard. These methods include membrane processes, coagulation, active alumina and ion exchange. Before choosing the appropriate method, certain issues such as treatment costs, treatment efficiency, and the complexity of the technology and knowledge necessary to use that technology and the disposal of the resulting waste must be taken into account. The advantage of the reverse osmosis process, compared to other methods, is high removal efficiency, lack of chemicals and less attention of expert and full-time operator [22]. The results of this study showed that the concentration of arsenic in water of Rafsanjan was eight times higher than the global standard. The arsenic removal efficiency of the treatment device was 86.7%, and the concentration of arsenic in the outlet water was reduced to standard level, and the lead concentration, in addition to being lower than the permissible limit in the inlet water, was reduced by 99% in the outlet water. Lin et al. used two methods of reverse osmosis and distillation at the point-of-consumption to remove arsenic from groundwater. The results showed that both methods have been effective in removing arsenic from the actual groundwater as well as artificial methods. Arsenic levels in the outlet water samples reduced to the standard limits and the arsenic removal efficiency was up to 99%. Although the efficiency of both methods was enhanced by increasing concentration; although the relationship between efficiency and concentration was not significant [31].

Mozafarian et al. investigated the arsenic removal efficiency of reverse osmosis process from water with five different types of membranes, and found that the highest arsenic removal efficiency of the membrane was 95% [32]. Walker et al. investigated the effectiveness of home reverse osmosis systems for groundwater containing high arsenic levels. They showed that arsenic removal efficiency was higher than 95% [33]. Mokhtari et al. reported that the reverse osmosis process was effective to remove arsenic from drinking water, and had good removal efficiency (more than 95%)

in surface and ground waters with arsenic concentration up to 2 mg/l [34]. These results also confirmed our results. Malakootian et al. investigated the sources of drinking water in the Rafsanjan plain. The existence of volcanic rocks in the region and the presence of sulfide compounds and streaks in these rocks is one of the reasons for the release of heavy metals. Arsenic, lead, and cadmium have similar sulfur properties and replace them when they form sulfides [34]. By the adaptation of the metamorphic map of the area and the regions with the same arsenic concentrations, it could be clearly observed that more volcanic rocks (andesite) were found in places where the concentration of arsenic is higher than standard. Because of the use of pesticides and herbicides containing arsenic in agriculture in Rafsanjan, the lack of a wastewater treatment system for metallurgical industries, and the chemical and cellulose industries, metals enter into wells and then penetrate into groundwater [34].

The results of studies have shown that Rafsanjan water pollution by arsenic is due to both natural and human activities, which is consistent with the results of the present research. The concentrations of copper in all studied samples were lower than the standard recommended by the National Iranian Water Organization and the WHO. Malakootian et al. studied the southern Rafsanjan plain. They showed that due to the potential presence of copper in Bardsir and Rafsanjan regions' soil as well as the presence of sulfide streaks in the region, the amount of copper was even lower than that recommended by the National Iranian Water Organization and the WHO [34]. The results of the assessment of groundwater pollution in the Kerman showed that the concentrations of lead and cadmium in the water samples were higher than the standard limits for drinking water and those of copper and zinc was lower than the standard [34]. Nitzsche et al. investigated the removal of arsenic from drinking water by using a sand filter system in Vietnam in 2015. Results showed the efficient and reliable performance of the system, with an arsenic removal efficiency of 95% [35].

Conclusion

EC and pH values of inlet water were in the standard limits, although arsenic levels were higher than the permissible limits and other parameters such as total hardness, calcium, magnesium, sodium as well as metals copper, zinc and lead were lower than standard limits. All parameters in the outlet water samples were significantly lower compared to those in the inlet water samples. The results of current study showed that home water treatment devices were highly efficient to remove the physicochemical parameters of water; the devices could reduce the concentrations of the parameters up to those under the standard limits, which is not desirable for some elements. However, due to a significant decrease in the concentration of arsenic, it is suggested that specific filters can be used at the inlet municipal water to adsorb heavy metals, especially arsenic.

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Conflict of interest

There is no conflict of interest.

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