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Assessment of Heavy Metal Concentrations in Water Purifier Devices in Rafsanjan City

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ABSTRACT

Introduction: Heavy metals (HMs) are one of the most important and dangerous pollutants in water resources. This study aimed to determine the HMs concentrations in city water purifier devices or stations in Rafsanjan, Iran in 2022.

Materials and Methods: This study was conducted descriptively and on a laboratory scale on the input and output of 16 city water purifier devices stations in Rafsanjan in the summer of 2022. Heavy metals and other metals including arsenic (As), lead (Pb), chromium (Cr), copper (Cu), zinc (Zn), iron (Fe), magnesium (Mg), calcium (Ca), sodium (Na), and potassium (K) were tested by inductively coupled plasma mass spectrophotometry (ICP-MS). Also, t-test statistical analysis was used by SPSS software.

Results: The mean concentrations of HMs in the output of city water purifier devices for As, Pb, Cr, Cu, and Zn were ≤ 1, 2.84 ± 0.71, 8.48 ± 1.51, 2.51 ± 1.55, and 18.58 ± 9.24 µg/L, respectively. The difference between the output of water purifier devices and standard values for As, Cr, and Cu was significant ($p \leq 0.001$). Other metals concentrations in the output of water purifier devices for Fe, Mg, Ca, Na, and K were 0.03 ± 0.008, 6.72 ± 0.92, 8.38 ± 1.71, 64.11 ± 2.56, and 2.34 ± 0.08 µg/L, respectively. The HMs removal efficiency of city water purifier devices for As, Cu, and Pb were $\geq 99\%$, 83.33%, and 56.33%, respectively.

Conclusion: The HMs removal efficiency of city water purifier devices stations in Rafsanjan City was appropriate due to the use of filters containing alumina and iron hydroxide media.

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Introduction

Water is one of the most important and precious natural resources that is essential for the life of all creatures, and it is a guarantee for the economic and social development of countries all over the world [1, 2]. Access to safe drinking water is key to sustainable development and essential for food production and community health [3, 4]. Access to safe and clean drinking water is one of the most important issues related to health worldwide, especially in developing countries [5, 6]. Health risks may increase due to

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the consumption of drinking water contaminated with various pollutants such as heavy metals (HMs), organic pollutants, and microbial and viral pathogens [7, 8]. According to the World Health Organization (WHO), nearly 2 billion people in the world use unsafe and contaminated drinking water sources [9]. Water-borne diseases are the biggest health threat and among the most common and emerging diseases in different parts of the world. About 70-80% of the health problems in developing countries and more than 80% of the infectious and chronic diseases in the world are caused by the consumption of unhealthy and polluted water [10, 11].

The physical, chemical, and microbial properties of drinking water are very important in ensuring the health and safety of drinking water and the level of consumer satisfaction [12]. Among the chemical parameters in drinking water, anions and cations, chemicals, HMs, and toxins are significant and important [13]. Excessive amounts of these contaminants in drinking water can cause adverse effects on the health of living organisms and consumers [14].

HMs such as arsenic (As), lead (Pb), mercury (Hg), cadmium (Cd), nickel (Ni) and chromium (Cr) are among the most important and dangerous pollutants of water resources [15], which can be caused by human activities such as the use of pesticides in agriculture, industrial effluents, and mining activities. They can also enter water sources naturally, due to the weathering of mineral rocks or earth's crust [16-18]. HMs are harmful to the health of animals and the environment, due to properties such as high stability and bioaccumulation in the body of living beings [19, 20]. Exposure to low concentrations of these metals directly or indirectly through the food chain can cause bioaccumulation of these metals in the body tissues of living organisms, leading to serious health problems and even death due to their high toxicity [17, 21, 22]. Long-term consumption of drinking water containing HMs can cause many acute and chronic effects, including the occurrence of various types of poisoning, cancers, and problems with the immune, nervous, and endocrine systems (including nephrotoxicity and hepatotoxicity) [23-25]. More than 90% of all types of cancers in the world are caused by carcinogenic compounds such as HMs through the consumption of drinking water [26, 27]. Therefore, it is necessary to control and monitor the quality of drinking water to remove, if necessary, harmful pollutants from it and make safe and clean water available to the public and communities [27]. One way to reduce pollution and remove pollutants from drinking water is to use drinking water purifier devices devices in cities [28].

Water purifier devices devices or water purifier devices usually use a wide range of purification systems to remove pollutants from drinking water. These include a variety of surface absorption processes, ion exchange, and membrane filtration methods such as reverse osmosis, nanofiltration, and ultrafiltration [29]. Each method and system has advantages and disadvantages, and among them, membrane processes are the most widely used. The most crucial disadvantage of this method is the removal of all solutes from drinking water. Therefore, systems that can both remove heavy and toxic metals and keep solutes in the water have attracted much attention from researchers [30].

In the southeastern parts of Iran and Rafsanjan city (geographical location from 55°, 0'E to 53°, 46'E and 30°, 5'N to 31°, 5'N), ground water resources are considered the main resource of drinking water for communities, and due to the indiscriminate extraction of these resources, the quality of water has gradually decreased. Today, the quality of drinking water in the distribution network of Rafsanjan city, especially in terms of mineral and metal pollutants, does not have suitable conditions; therefore, drinking water purifying devices have been installed in the city for public use [3]. Therefore, considering that water quality is one of the main concerns of people, which is directly related to human health and well-being, and considering the lack of detailed information on the efficiency of city water purifier devices in Rafsanjan, this study aimed to determine the changes of HMs concentrations in city water purifier devices stations in Rafsanjan in 2022.

Materials and Methods

This study was conducted descriptively and on a laboratory scale on the input and output of 16 points water purifier devices in Rafsanjan in the summer of 2022. In this study, all water purifier stations in Rafsanjan (16 devices or stations) were selected as sampling stations. A total of 32 water samples were collected from input and output taps of city water purifier devices according to sampling standards into one liter polyethylene containers. In this study, HMs such as As, Pb, Cr, Cu, Zn, Fe, Mg, Ca, Na, and K were measured and analyzed. In order to measure metals, nitric acid (Ultra-Pure ≥ 99%) was added to the collected water samples to bring their pH to less than 2. Samples were then transferred to the laboratory and analyzed using an ICP-MS (inductively coupled plasma-mass spectrometry) device (Agilent Series Hp 4500, USA) with limit of detection (LOD) of 0.05-0.5 µg/L. All measurements were done in triplicate [26].

In this study, after collecting and entering the data into SPSS software version 18, one-sample t-test was used to analyze the data and compare the mean concentrations of the parameters with the standard, and paired samples t-test was used to compare the changes in concentrations of metals in the input and output of the device.

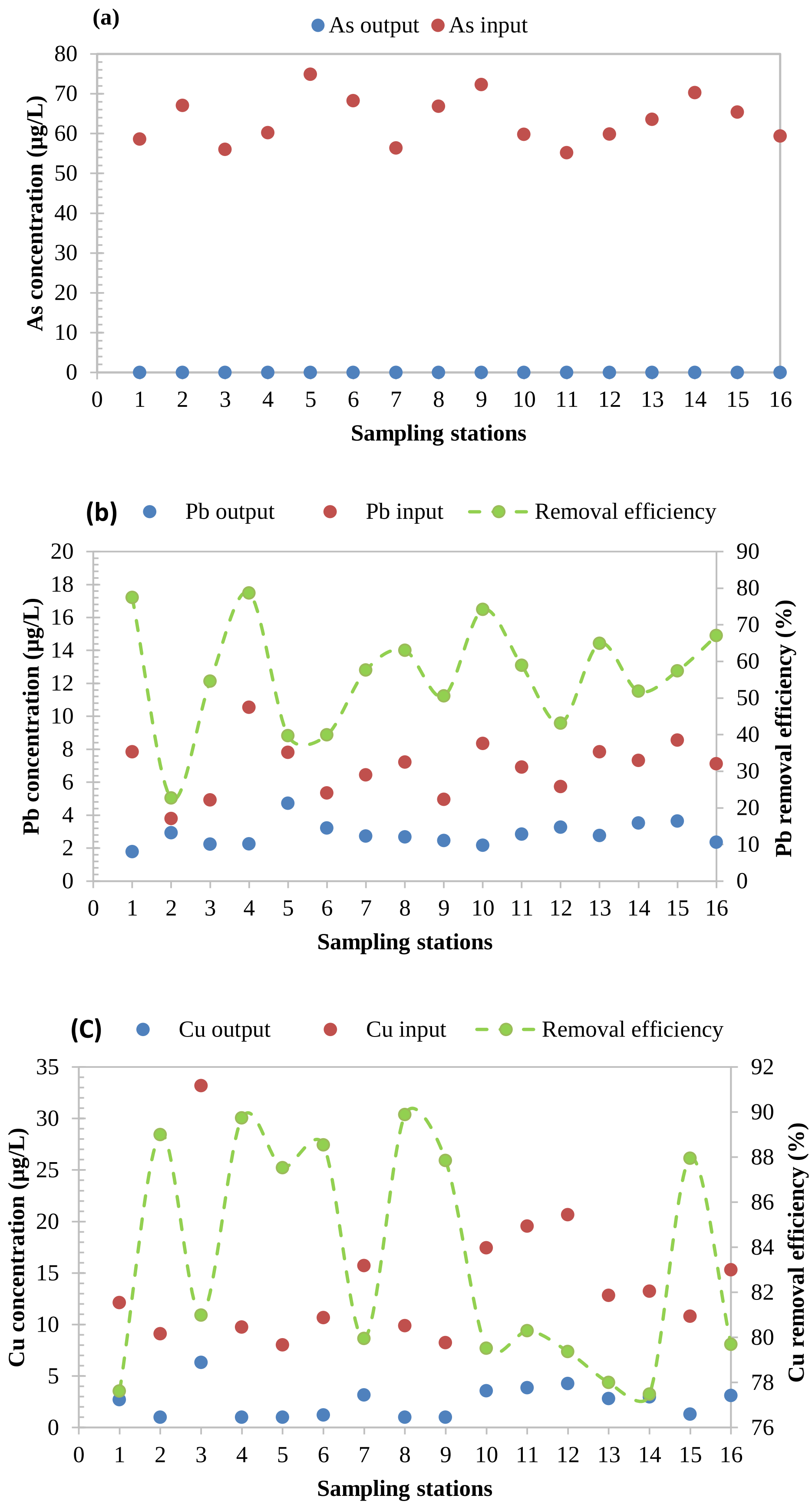
Ethical Issue

The ethical code for this research is IR.RUMS.REC.1399.173 confirmed by Ethics Committee of Rafsanjan University of Medical Sciences, Rafsanjan, Iran.

Results

Changes in HMs concentrations

Figure 1 shows HMs concentrations, including As (1.a), Pb (1.b), Cr (1.c), Cu (1.d), and Zn (1.e) in input and output of city water purifier devices in Rafsanjan and the devices efficiencies. The mean concentrations of HMs entering the city water purifier devices for As, Pb, Cr, Cu, and Zn were 63.35 ± 6.11, 6.91 ± 1.68, 13.27 ± 2.08, 14.15 ± 6.38 and 32.76 ± 11.81 µg/L, respectively. The mean concentrations of HMs output from city water purifier devices for As, Pb, Cr, Cu, and Zn were ≤ 1, 2.84 ± 0.71, 8.48 ± 1.51, 2.51 ± 1.55, and 18.58 ± 9.24 µg/L, respectively. Also, the mean removal efficiencies of HMs of city water purifier devices for As, Pb, Cr, Cu, and Zn were ≥ 99%, 56.33 ± 15.08%, 34.56 ± 15.79%, 83.33 ± 4.95%, and 42.74 ± 16.82%, respectively. The results of the paired sample t-test statistical analysis showed that changes in metals concentrations in the input and output of city water purifier devices were statistically significant for As, Cu, and Zn ($p \leq 0.001$) and were not significant for Pb and Cr ($p > 0.05$). Also, the results of one sample t-test statistical analysis showed that the difference between the output of city water purifier devices and the standard values for metals As, Cr, and Cu was statistically significant ($p \leq 0.001$). Also, the concentration of Cd in the input and output of city water purifier devices was less than 1 µg/L.


(a)
As output
As input
As concentration (µg/L)
Sampling stations
(b)
Pb output
Pb input
Removal efficiency
Pb concentration (µg/L)
Pb removal efficiency (%)
Sampling stations
(C)
Cu output
Cu input
Removal efficiency
Cu concentration (µg/L)
Cu removal efficiency (%)
Sampling stations

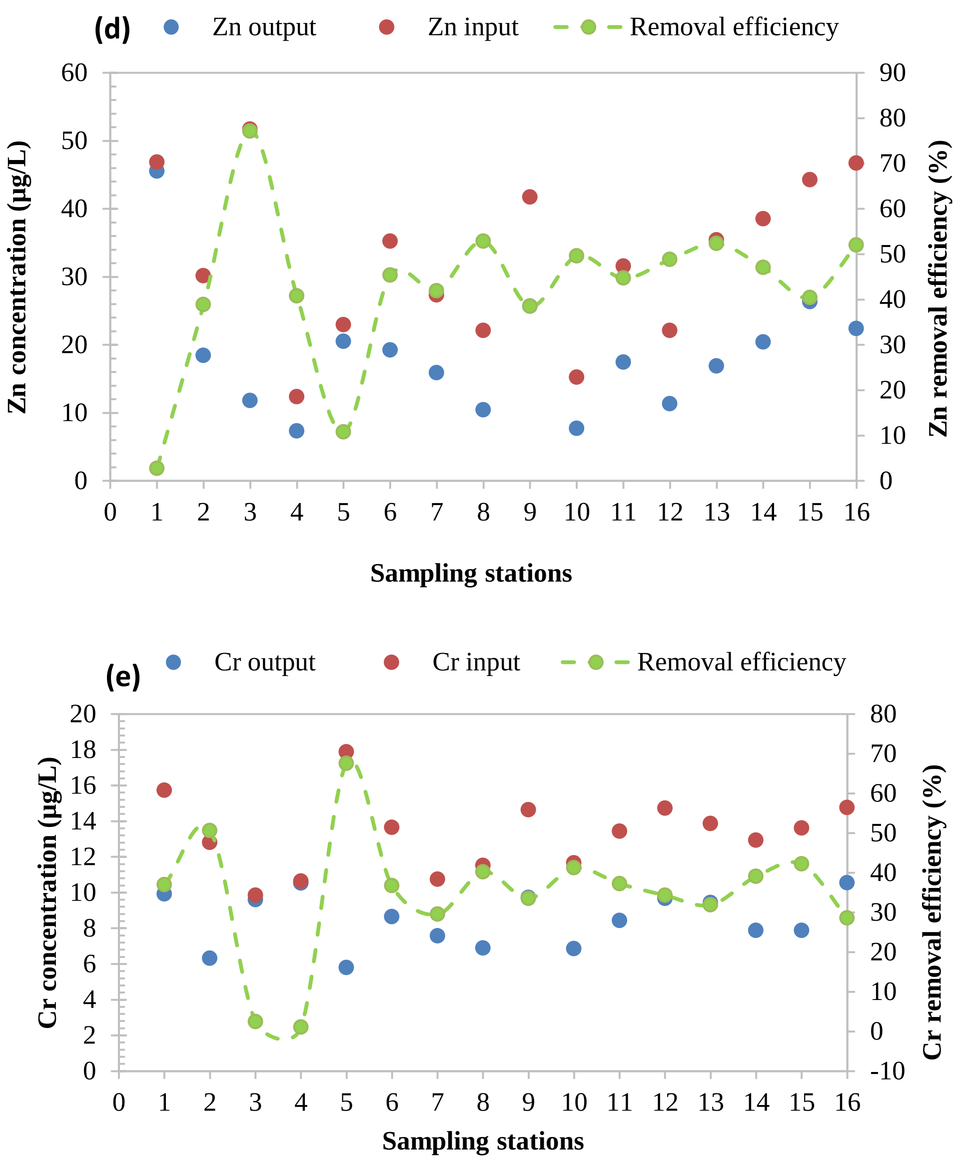


Figure 1: HMs concentrations changes for (a) As, (b) Pb, (c) Cr, (d) Cu, and (e) Zn in input and output of city water purifier devices in Rafsanjan

Changes in other metals concentrations

Figure 2 shows the concentrations of other metals including Fe (2a), Mg (2b), Ca (2c), Na (2d), and k (2e) in input and output of city water purifier devices and the devicesefficiencies. The mean concentrations of these metals in input of city water purifier devices for Fe, Mg, Ca, Na, and k were 0.076 ± 0.016, 11.31 ± 1.34, 24.28 ± 1.64, 123.42 ± 13.23, and 3.23 ± 0.24 mg/L, respectively. The mean concentrations of these metals in output of city water purifier devices for Fe, Mg, Ca, Na, and k were 0.03 ± 0.008, 6.72 ± 0.92, 8.38 ± 1.71, 64.11 ± 2.56, and 2.34 ± 0.08 mg/L, respectively. Also, the mean removal efficiencies of these metals in city water purifier devices for Fe, Mg, Ca, Na, and k were 58.68 ± 13.91%, 40.21 ± 7.94%, 65.71 ± 5.18%, 47.54 ± 5.41%, and 27.08 ± 26.76%, respectively. The results of statistical analysis of paired samples t-test showed that changes in the concentrations of metals input and output of city water purifier devices were statistically significant for Mg, Ca, and Na ($p \leq 0.001$) and were not significant for Fe and K ($p > 0.05$).

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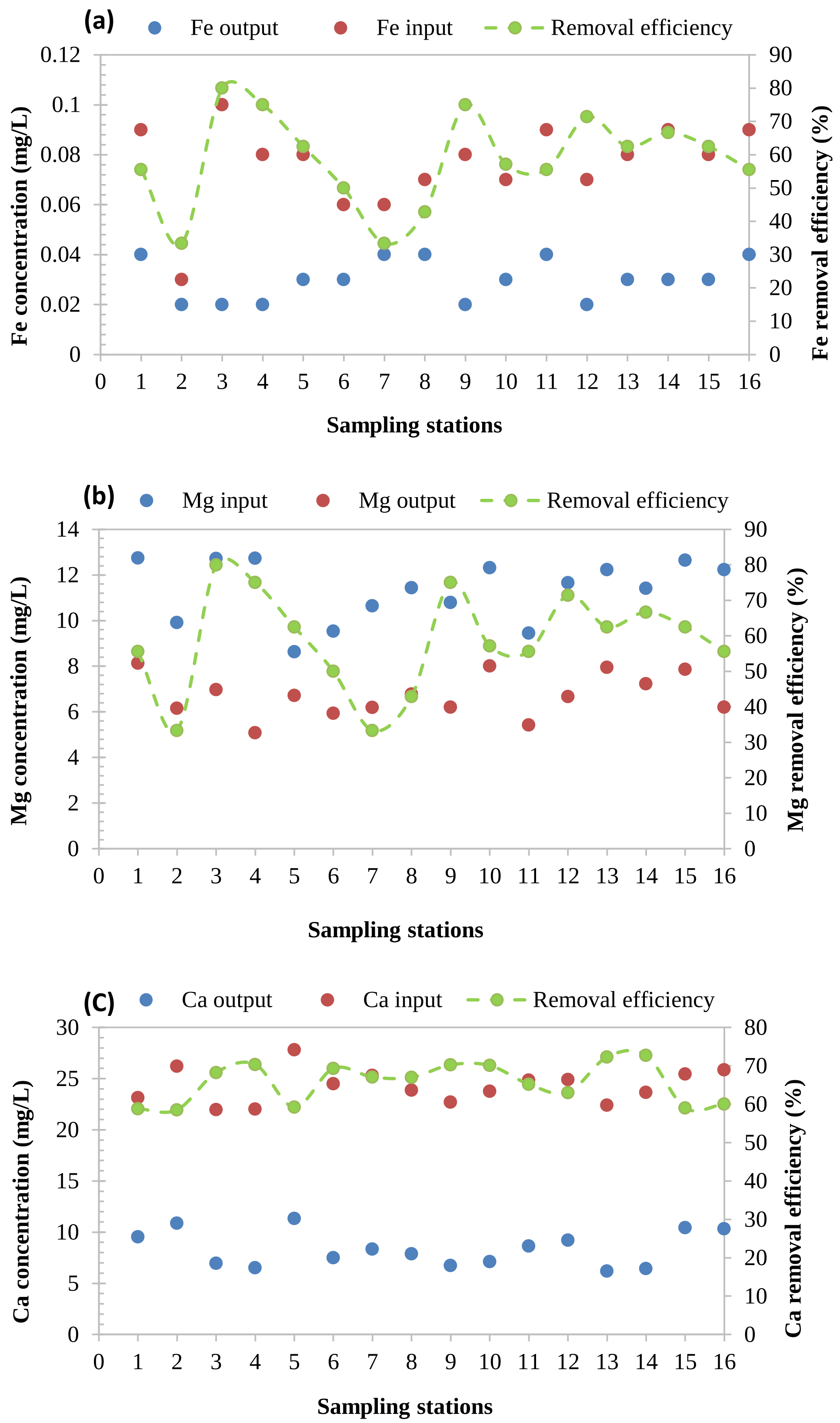
(a)
Fe output
Fe input
Removal efficiency
Fe concentration (mg/L)
Fe removal efficiency (%)
Sampling stations
(b)
Mg input
Mg output
Removal efficiency
Mg concentration (mg/L)
Mg removal efficiency (%)
Sampling stations
(C)
Ca output
Ca input
Removal efficiency
Ca concentration (mg/L)
Ca removal efficiency (%)
Sampling stations

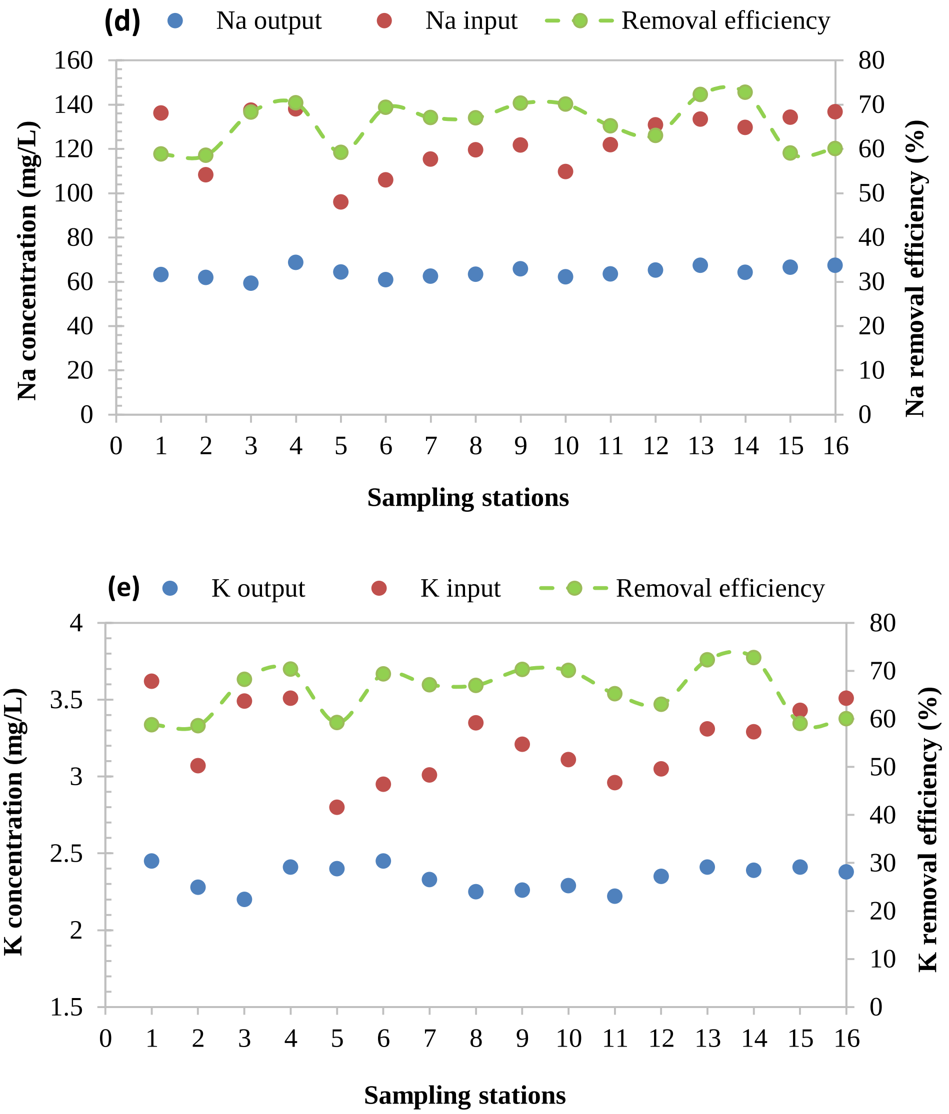

Figure 2: HMs concentration changes for (a) Fe, (b) Mg, (c) Ca, (d) Na, and (e) k in input and output of city water purifier devices in Rafsanjan

Discussion

One of the most important environmental problems in Rafsanjan city (and in general in the southeast of Iran) is the presence of HMs in water sources due to the type of aquifer bed and mineral stones in these areas. Many people in these areas procure safe water for drinking and cooking purposes using household water purifier devices or city water purifier devices [6, 31]. The study by Fahiminia et al. on the efficiency of household water purifier devices in Qom city shows that the efficiency of these systems to remove HMs from drinking water varies from 5% for Al to 86% for Cd, and the mean removal efficiency of these devices was 43%. However, Pb concentration in both input and output water was high, indicating that these devices are not able to completely remove HMs from drinking water [30]. The study by Velayatzadeh et al. on the effect of household water purification devices on the concentration of metals in Ahvaz drinking water shows that the highest removal efficiency was for cobalt (Co) and Cr (66.66%) [32]. A study conducted by Talebzadeh and Dehghanizadeh on the physical and chemical properties of output water of household water purifier devices showed that the mean removal

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efficiencies of Pb and Cu was 47% and 49%, respectively [33]. Comparing the results of the present study with similar studies shows that household water purifier devices with membrane filtration and reverse osmosis systems alone are not able to remove HMs completely. Studies have shown that in order to increase the efficiency of these systems, along with membrane processes, other processes such as membrane ion exchange or filters containing various types of absorbents or metal hydroxides can also be used in a multi-stage system. In the study conducted by Chen et al., zeolite-cotton filters were used as a low-cost system for purifying and removing HMs from drinking water at home, and it was shown that this filter could remove contaminated water containing HMs (Cu^{2+}, Cd^{2+}, and Pb^{2}) and reduce their concentration to less than 5 ppb [7].

In the present study, removal efficiencies for other metals in city water purifier devices in Rafsanjan was 65.71% for Ca, 58.68% for Fe, 47.54% for Na, and 40.21% for Mg. The study by Velayatzadeh et al. showed that removal efficiencies of metals in output of water purification devices in Ahvaz was 47.22% for Fe, 30.46% for Na, 17.81% for Ca, and 21.01% for Mg, and concentrations of these metals in the output was lower than the standard values [32]. The study conducted by Aghababaei on the chemical quality of drinking water output from private water desalination devices of Saveh city showed that the mean concentrations of Ca, Mg, K, and Na were 37.28, 2.45, 0.37, and 68.23 mg/L, respectively [34]. In a study by Talebzadeh and Dehghanizadeh, the mean removal efficiency of Fe and Zn by household water purifier devices were 47% and 79%, respectively [33]. In a study conducted by Malakootian et al. on the efficiency of household water purifier devices in removing cations and anions from drinking water in Kerman, the results showed that the mean removal efficiencies of Ca, Mg, and Na , in 14 brands of devices, were 61.21%, 78.98%, and 32.59%, respectively [35]. A comparison of the output water quality in city water purifier devices in Rafsanjan with other domestic and urban water purification systems in other studies shows that the quality of input water had a significant effect on the efficiencies of these systems. However, the overall metal removal efficiencies in this study were relatively higher than similar studies, which could be due to the type of water purification systems in Rafsanjan city. City water purifier devices in Rafsanjan are a commercial system and have two separate purification stages. Water from urban distribution network first enters filters containing alumina and iron hydroxide media and then enters the reverse osmosis membrane system in the second step. After that, the output purified water is ready for human consumption. Therefore, it can be said that this system has been effective in removing metals, especially toxic HMs. Moreover, due to the presence of iron hydroxide compounds in the filters, the efficiency of this system in removing As has been much higher than other metals [6]. Pourjamali et al. investigated the efficiency of household water purifier devices in removing HMs from drinking water in Rafsanjan. Their results showed that the highest removal efficiencies were for Cu, Zn, and As. The mean concentration of As decreased from 81.34 to 10.87 ppb [31], which was less efficient compared to the existing water purification devices in Rafsanjan. In order to improve the efficiency of domestic and urban water purification devices, especially with the aim of completely removing toxic HMs, membrane processes containing nanoparticles can be used as absorbents in these filters. It can improve the efficiency of these systems, especially in removing HMs [36]. It should also be taken into account that membrane processes such as reverse osmosis also severely reduce all valuable solutes and ions in water, and as a result, the use of mineral filters after these systems is essential to re-inject mineral materials into the output water.

Conclusion

In this study, the concentrations of heavy and toxic metals as well as other metals in the output of city water purifier devices or stations in Rafsanjan were significantly lower than their concentrations in input of these devices. Moreover, HMs mean concentrations were lower than the maximum level of the WHO standard. Also, the removal efficiencies of heavy and toxic metals, especially for As, Pb, and Cu were suitable due to the two-stage process and the use of filters containing alumina and iron hydroxide media and the reverse osmosis membrane system. It is recommended to use mineral filters after these systems in order to add valuable mineral materials to the water output. Also, continuous monitoring and control of these systems is necessary to restore or replace these filters.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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