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Performance Evaluation of Point-Of-Use Drinking Water Treatment Units in Removal of Heavy Metals and Dissolved Solids from Drinking Water Supply in Tabriz

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ABSTRACT

Introduction: Application of point-of-use (POU) drinking water treatment units is expanding across the world due to the increased concerns about the adverse health effects of water pollution. The main treatment systems of these devices are mostly activated carbon and nano-filter or reverse osmosis.
Materials and Methods: This study was conducted to evaluate the effect of using POU units on physical and chemical characteristics of water supply by people of Tabriz. The results were compared with national drinking water standards of Iran. A total of 60 samples were collected from 30 devices and analyzed for physical and chemical parameters especially heavy metals.
Results: According to the findings, the physical and chemical parameters of the treated water were acceptable. Concentration of Pb was significantly higher than standards in the input water and effluent obtained from units.
Conclusion: Although drinking water plays an indirect role in providing minerals for the body, consumers of these devices should be made aware of the reduced intake of minerals through drinking water. Considering the efficiency of household POU drinking water treatment units to reduce heavy metals that have health effects on humans, adequate supervision should be performed on the supply of standard and suitable products in the market.

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Introduction

Nowadays, drinking water treatment is often done only by conventional physical methods such as sedimentation and filtration, but this treatment rate is not enough to remove salts and water soluble toxic substances such as nitrates, agricultural toxins, and heavy metals.

In addition, due to the use of chlorine for disinfection, creation of secondary disinfection products that contain toxic and carcinogenic compounds is also likely. There is also the risk of contamination of treated drinking water during storage, transfer and distribution [1, 2].

Heavy metals such as lead, copper and zinc can enter the water from drinking water distribution and piping systems. Studies on drinking water in different parts of Iran have shown that the amounts of heavy metals are higher than the limits permitted [3, 4].

The World Health Organization (WHO) announced that local water treatment and safe storage, as a key component of water health and health programs, are essential for significant reduction in waterborne diseases, especially in vulnerable populations. POU drinking water treatment units include household water treatment devices [3].

These devices are often based on membrane technologies such as nano-filters, reverse osmosis and activated carbon adsorbents. The use of POU filtration systems has become widespread in recent years.

Many people have made it an essential part of their health promotion because of the propaganda or lack of trust in these devices, and their use is increasing on a daily basis. However, the inefficiency and fraud of the device's filters or the lack of drinking water standards can make them useless and, in some cases, harmful by increasing water bacteriological density [5].

Few studies have been conducted on the performance of these devices with respect to removal of the physical and chemical parameters of drinking water in Iran [6, 7].

In the conducted studies, the removal efficiency of heavy metals and the change in the chemical properties of water in terms of type and facies have been *less* frequently addressed.

Therefore, the purpose of this study is to evaluate the physical and chemical quality of treated water by household water treatment systems in comparison with national standards and the degree of change in the type and facies of the effluent so that the necessity and usefulness of these devices could be elucidated.

Materials and Methods

This cross-sectional, descriptive study was conducted to evaluate the quality of treated water obtained from household water treatment units in Tabriz. A total of 60 water samples from 30 household water treatment units were collected and three 1000 ml samples were simultaneously collected from the input water and effluent of the devices and analyzed for physical and chemical parameters.

The number of steps and the processes used in household water treatment units are presented in Table 1.

Samples collected for analysis of the physical and chemical parameters were stored in polyethylene containers, and the date, hour, and location of sampling, residual chlorine, and pH at the time of sampling was recorded and the samples were transferred to the laboratory of Tabriz University of Medical Sciences immediately.

The measured parameters included the residual free chlorine, turbidity, pH, color, EC, total alkalinity, bicarbonate, total hardness, calcium, magnesium, sodium, potassium, sulfate, nitrate, nitrite, chloride and heavy metals such as iron, lead, copper and zinc. The residual chlorine, pH and temperature at the time of sampling were also measured.

The parameters of water samples were measured according to the instructions offered in the textbook of standard drinking water testing methods [8].

In order to measure nitrate, nitrite and sulfate, spectrophotometer at, respectively, 227, 543, and 420 nm was used.

Titration was used to measure hardness, calcium, magnesium, alkalinity and chloride. Flame photometry was used to measure sodium and potassium.

The optometry was used to measure turbidity and the conductivity meter to measure electrical conductivity.

For analysis of heavy metals, water samples were collected in glass bottles. In order to stabilize the samples and decrease the pH to below 2, 0.5 ml of the pure nitric acid was poured into the water samples.

Lead and copper levels in the water samples were measured by an atomic absorption device using graphite furnace (210 VGP Buck Scientific) and zinc level by flame atomic absorption (CTA-2000 A.A.S).

A kit was used to measure iron level. In accordance with the instructions of the kit's manufacturer, the water samples were first mixed with the respective solutions and after a certain time, the resulting color was compared with the specified color spectrum and expressed in mg/l. The range of measurements by kit is from 0.2 to 1 mg/l.

The results were analyzed using the SPSS version 16. In addition to descriptive statistics, statistical tests were used to analyze the data on the input water and effluent of the devices. The Kolmogorov-Smirnov test was used to investigate the normal distribution of data and paired-sample *t*-test to compare the mean values before and after treatment using the device.

Table 1: Characteristics of household water treatment units

Ion transfer Resin	Mineral Filter	Post-Activated Carbon	Membrane Filter (RO & NF)	Pre-Activated Carbon	Polypropylene Filter	Number of steps	Sample Number
*	*	*	*	*	*	6	1-7
-	*	*	*	*	*	5	8
-	-	-	*	*	*	3	9
*	*	*	*	*	*	6	10-16
**	**	**	**	**	**	6	17
*	*	*	*	*	*	6	18-23
**	**	**	**	**	**	6	24
-	*	*	*	*	*	5	25
*	*	*	*	*	*	6	26-27
**	**	**	**	**	**	6	28-29
*	*	*	*	*	*	6	30

** The used technology is GAC.

Results

Table 2 summarizes the results on the parameters in the input water and effluent of the units. Compared to the national standards, all measured parameters are below the standard. All parameters in the effluent of household water treatment units were significantly reduced compared to the input water ($P < 0.05$).

About 67% of the water samples were hard (150-300 mg/l calcium carbonate) and the rest relatively hard (75-150 mg/l calcium carbonate). Of the water samples from the units, 93% were light (0-75 mg/l calcium carbonate). The results of previous studies in different cities of Iran on the performance of these units regarding the removal of physical and chemical parameters were desirable [6, 7, 9].

The Piper and Stiff diagrams were used to study the chemical composition of water to analyze the input water and effluent (Figures 1 and 2).

According to the Piper diagram, the water samples were divided into three hydrochemical facies Mg^{2+}, Ca^{2+}, and Cl^- based on cations and three type of bicarbonate, sulfate and chlorine based on anions.

The Piper diagram indicates that the input water of the units is Ca-Mg-Cl type. According to the Stiff diagram, Results indicate irregular patterns that calcium and bicarbonate are predominant ions. The diagrams illustrate significantly different water ion composition within the city.

Fig. 2 presents the hydrochemical faces of the water samples obtained from inlet and outlet of the HWTDs using piper diagram. As clearly revealed by the piper plots, most of the various water sources of the area have distinct hydrochemical faces. The central diamond diagram helps to determine the hydro-chemical faces (mixing property). Combined concentrations of alkali metals (Ca + Mg), HCO3, SO4 and Cl are the main ions. The piper diagram also indicates the dominance of alkaline water (Ca + Mg + HCO3) and mixed water (Ca + Na + Cl) in the inlet water samples. At the all inlet samples weak acidic roots are greater than the strong acidic roots (HCO3 > Cl + SO4).

As indicated on the central diamond, all the inlet samples of the study area are categorized into 2 hydro chemical faces of Ca + Mg + HCO3 and Ca + Na + HCO3 from the seven regions.

The Piper diagram shows that most of the outlet water samples fall in the field of mixed alkaline and alkaline earth metals (Na + Ca), while the anions HCO_3 and Cl dominate over SO_4 ions.

Table 2: Physical properties of water and the amounts of non-toxic mineral chemicals in inlet and outlet of household point of use water treatment systems

Parameter*	In			Out			Admissible Limit	Removal efficiency	*P* value (Input-Output)
	Average	Minimum	Maximum	Average	Minimum	Maximum			
Residual chlorine	0.2	0	0.4	0	0	0	0.2	-	-
pH	7.4	7.1	7.8	6.97	6.7	7.3	6.5-9	-	0.006
EC	464.7	210	690.5	69	12	230	-	85	0.000
(NTU)Turbidity	0.8	0.2	3.3	0.45	0.17	1.05	5	27	0.006
Total hardness (as CaCO3-)	186	100	270	23	0	88	200	87	0.000
Ca^{++}	48	24	77	5	0	25	300	90	0.000
Mg^{++}	18	6.3	78	3	0	8	30	79	0.000
Na^{+}	32.4	11.5	54	10	0.01	42.35	200	71	0.000
K^{+}	3.3	0.75	4.5	0.6	0	3.2	-	83	0.000
Alkalinity (as HCO3–)	126	32	172	24	8	88	-	80	0.000
HCO^{3-}	153	39	210	30	10	107.4	-	80	0.000
SO^{4-}	58	14	117	4	0	21	250	92	0.000
Cl^{-}	44	6	110	8.3	0	72	250	79	0.000
NO^{3-}	12.4	3	27	4	0	17.5	-	72	0.000
NO^{2-}	0	0	0	0	0	0	-	-	-

* All parameters measuring unit was mg/l: except pH (no unite); turbidity (NTU); Electric conductivity (µs/cm)

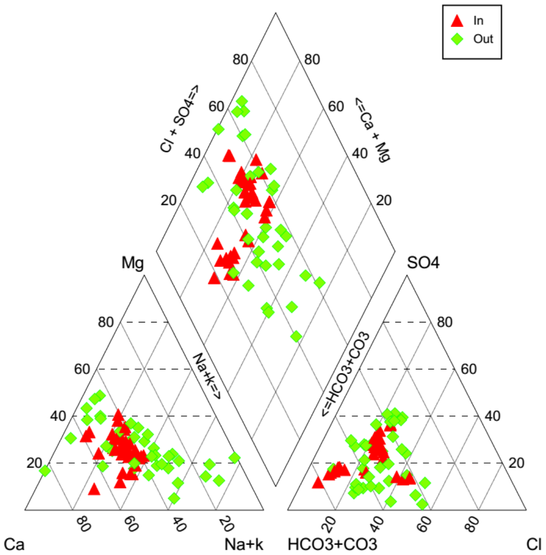

Figure 1: Major chemical constituents in trilinear (Piper) diagram from inlet (In) and outlet (Out) of the HWTDs samples in the city of Tabiz.

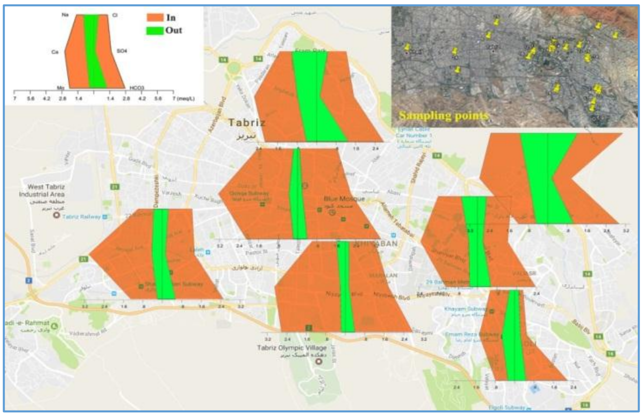

Figure 2: Distribution pattern of sampled HWTDs in the city and the performance of devices on the water hydrochemical faces in theseven regions

Table 3 shows the amounts of heavy metals in input water and effluent obtained from the household water treatment units. The amounts of iron, zinc and copper were lower than the national standards of Iran, but the lead content in some samples was higher than the national standard. The statistical test showed that all parameters except for zinc were significantly different between input water and effluent ($P < 0.05$).

Table 3: Non-toxic and toxic heavy metals concentrations in in inlet and outlet of household point of use water treatment systems

Parameter	In (mg/l)			Out (mg/l)			Admissible Limit	Removal efficiency	*P* value (Input-Output)
	Average	Minimum	Maximum	Average	Minimum	Maximum			
Iron	0.13	0	0.57	0.04	0	0.1	0.3	47	0.001
Zinc	0.53	0.03	2.2	0.03	0	0.11	3	79	0.114
Cooper	0.012	0.00765	0.017	0.0057	0.001	0.0113	1	49	0.003
lead	0.0046	0.0075	0.02	0.0034	0.0018	0.0115	0.01*	47	0.001

* The Maximum Contaminant Level by Iran national standards

Discussion

The results of this study showed that the physical and chemical parameters of the input water (distribution network) and effluent samples were within the standard range, which is consistent with the results of previous studies on household water treatment units [6, 10, 11]. The mean residual chlorine in the input water was 0.2 mg/l and in the effluent zero. The removal of the residual chlorine is due to the presence of activated carbon filter in these devices.

Main function of the activated carbon filters is mostly reduction of colloids, chlorine, color, tastes and odor [12, 13].

Also, disinfection by products can be removed with the membrane filters, granular activated carbon and advanced oxidation processes [14, 15].

In addition, activated carbon provides the required nutrients for bacterial growth by absorbing organic materials, and therefore, in the absence of free chlorine, the remaining water may contain a variety of opportunistic and pathogenic bacteria [5].

The results of this study indicated a low pH in the effluent obtained from household water treatment units ($P = 0.006$).

Reverse osmosis membranes are not able to remove CO_2 in water; therefore, water passing through the membrane has a low pH, which eliminates the buffering capacity of water.

The average amounts of magnesium and calcium in the input water were 18 and 48 mg/l, respectively, which decreased to 3 and 5 mg/l in the effluent, respectively.

Drinking water is one of the important sources of calcium and magnesium. Several studies have examined the relationship between water hardness and heart disease [16 - 20]. Total magnesium intake should be at least 450-500 mg/day, and drinking water should contain at least 25-50 mg/l magnesium [21].

Therefore, due to the need to receive magnesium and calcium through the water, household water treatment units seem to have a disadvantage, i.e., the removal of high levels of useful salts. Therefore, consumers of the household water treatment units should adopt certain strategies to receive these salts.

The presence of iron in the water transfer and distribution system can be due to the source of water, the use of iron salts in the conventional treatment of drinking water (coagulation process) or corrosion of pipes and facilities used in the water supply reservoir.

The lead removal efficiency in this study was 47%, which is twice as much as the removal efficiency obtained in the study of Fahiminia et al. and the results showed that POUs studied were unable to remove all heavy metals [6].

Conclusion

Due to the quality of drinking water in Tabriz and its compliance with national quality standards, the use of household water treatment units is not recommended. The use of these units also removes high amounts of useful salts. On the other hand, the complete removal of chlorine eliminates the conditions for secondary microbial contamination in the device's water storage tank.

However, given the efficiency of household water treatment units to reduce the intake of heavy metals from water that has health effects on humans, along with using these devices, it is advisable to supervise the provision of quality and standard products in the market; and the consumers of the household water treatment units should also consider the timely replacement of filters to increase their efficiency.

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Conflict of Interest

There is no conflict of interest for the authors.

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