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Assessment performance of three different water treatment processes in pilot-scale on the physicochemical quality of drinking water

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ABSTRACT

Recently, the quality of drinking water has been taken into consideration due to its important effects on human health and the environment worldwide. On the other hand, due to lack of resources and secondary water pollution, humans have to use different treatment methods to create safety. Therefore, we investigated the effect of several treatment methods, including household water treatment devices (HWTDs), boiling for 5 min and 5 h, on water quality in this study. Experiments were performed according to the standards in three replications on municipal drinking water. The parameters of turbidity, electrical conductivity, nitrate, nitrite, chlorine, phosphate, hardness, calcium and magnesium ions, and trihalomethanes were investigated according to standard methods after all three purification processes. The results revealed that boiling for a short time can decrease the harmful factors in the water to a desirable level. On the other hand, the amount of nitrite increased significantly due to prolonged water heating, which should be considered. Also, HWTDs methods could reduce water pollution significantly, but they are questionable due to the simultaneous removal of water salts. Hence, using a survey and comparing the present study results, short-term boiling of drinking water can be suggested as the best possible option.

Keywords: Physicochemical parameters; Drinking water; Boiling; Household water treatment devices; Treatment processes

1. Introduction

It is estimated that 1.1 billion people worldwide do not have access to safe drinking water. On the other hand, the existence of healthy drinking water for the survival of humans and living organisms is undeniable [1,2]. Nitrate is one of the most common impurities contaminating all drinking water sources. Potential sources of nitrate in groundwater include inadequate disposal of human and animal wastes, animal feed, manure and chemical fertilizers used to produce agricultural products on agricultural land, and natural sediment. High concentrations of nitrate in groundwater have been identified in many parts of Iran [3]. The World Health Organization has introduced a maximum allowable nitrate in 50 mg/L water distribution systems as NO_3. The amount of nitrate in drinking water should be adjusted because a high amount of this pollutant may cause severe illnesses and sometimes death, shortness of breath, methemoglobinemia or "blue baby" disease, bleeding in the spleen, and may also cause certain cancers, congenital disabilities and thyroid disorder [4–7]. Physicochemical properties are parameters that are used as an indicator of water quality. In addition to being transparent in appearance, clear, and free of turbidity, drinking water should also have optimal chemical quality. Physicochemical

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parameters significantly impact the popularity and general acceptance of water [8–10]. Therefore, it should be noted that the high concentration of water-soluble solids causes a taste of salinity and reduces consumer desire water drink to [11]. Trihalomethanes are another group of by-products of water disinfectants formed by the concentration of halogen atoms, the amount of organic matter in raw water, pH, and temperature. Besides, the most important of which are $CHCl_3$, $CHCL_2Br$, $CHCLBr_2$, and $CHBr_3$. The most dangerous effects of trihalomethanes, proven after several epidemiological studies, are bladder cancer, its impact on the reproductive system, low birth weight, liver and kidney damage, and circulatory disorders [12–14]. There are several ways to treat drinking water, especially removing or inactivating contaminants, including filtration, disinfection, and boiling. Boiling is one of the heating methods that are very efficient and eliminates human pathogens [15]. Filtration is another water treatment method that has been used variously since its development, including in hospitals and the food and pharmaceutical industries. By filtering, volatile organic compounds, sodium, nitrate, cysts, total dissolved solids (TDS), chemical contaminants, and petrochemicals will be removed [16,17].

Given that drinking water is consumed daily by consumers and has significant effects on human health, lack of water resources and permanent access to safe water is a serious problem. So, using an easy, low-cost, and efficient method for water purification seems essential. Therefore, we examined the efficiency of different purification processes on water quality to suggest the most effective method in this study.

2. Materials and methods

2.1. Sample preparation

In the boiling method for 5 min, the samples were heated and boiled for 5 min. For the second boiling step, the samples were boiled for 5 h after heating, then cooled and stored at 4°C for experiments.

2.2. Apparatus and methods

Household water treatment devices (HWTDs) were installed on the inlet of consumer water, and then a sample of purified water was taken from the outlet and examined for physicochemical parameters. This device was made in Thailand with a soft water brand that includes three stages of pre-treatment, two treatment pumps, two transformers, four membranes of 100 gal (each membrane has 13 layers), and activated carbon (Fig. 1).

2.2.1. Turbidity and electrical conductivity

The turbidity of the water sample was determined directly by a portable turbidity meter conductivity (Model: Lutron TU-2016, Made in Taiwan). Afterward, calibration was performed with a calibration solution by a conductor. The electrical conductivity was measured using a conductivity meter (Model Greisinger-GLM020, Made in Germany).

2.2.2. Nitrate, nitrite, fluoride, and phosphate

The samples were analyzed using reference methods (preparation of control samples and drawing of standard solution absorption curve) with a spectrophotometric DR4000 and DR2000 device (Made in USA). Nitrate, nitrite, fluoride, and phosphate were at a 400, 507, 570, and 890 nm wavelength, respectively [18].

2.2.3. Alkalinity, hardness, calcium, magnesium, and chloride

Alkalinity was determined by titration with 0.1 N sulfuric acid, and chloride was measured using the Mohr method (argentometry). Hardness was measured by titration with ethylenediaminetetraacetic acid [2]. The common

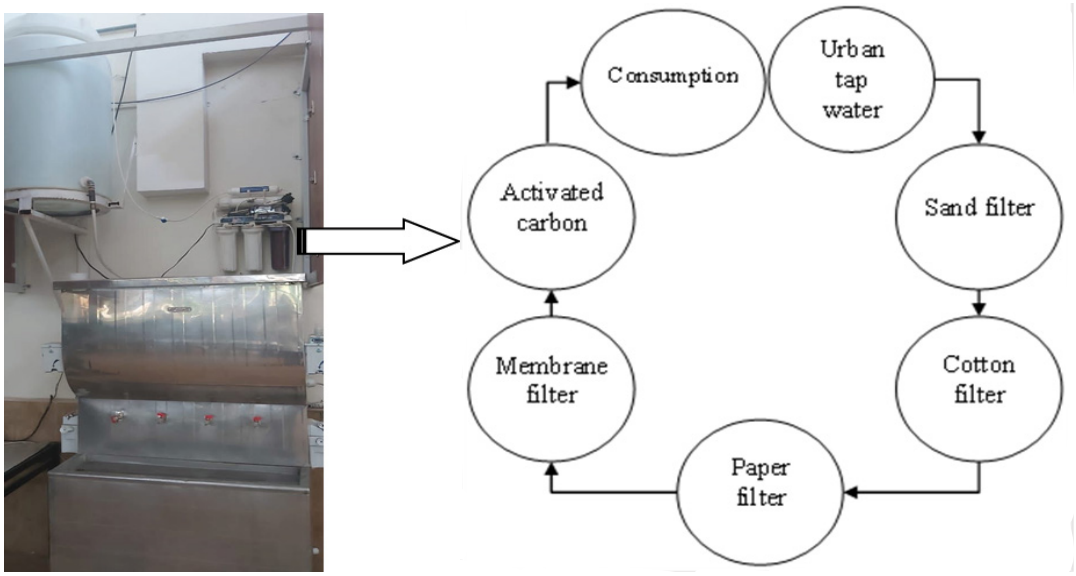

Fig. 1. Schematic of the HWTDs process.

cations (Ca^{++} and Mg^{++}) concentrations were then measured with the flame atomic absorption spectrometer, and chloride was measured according to standard methods to examine water and wastewater [18].

2.2.4. Trihalomethanes

According to the EPA, a sterilized 100-mL glass container washed with detergent and distilled water could be used to separate contaminants, followed by washing with deionized water and placing on dry heat at the temperature of 250°C for 30 min in order to sterilize and release the volatile compounds. Additionally, sodium thiosulfate was added to the sampling glasses to prevent the formation of more trihalomethanes (THMs) during the transportation and storage of the samples in the laboratory. The duration of sampling and analysis was less than 6 h. The concentration of THMs with the chloroform index was then measured using a mass spectrophotometer [2,19].

3. Results and discussion

As shown in Table 1, different processing of water treatment has different effects on pollutant reduction. Comparing the obtained results shows that the efficiency of boiling water for 5 min and HWTDs in removing turbidity was the same, and there was no significant difference (P-value > 0.05). Also, a comparison of the results of the present study with the national standards of Iran and the World Health Organization is presented in Table 1. However, since the water was boiled for a longer period (5 h), turbidity was significantly reduced (P-value < 0.05). Although this difference is significant, and efficiency of the process used, the ease of using the method and its operating costs are also important in choosing the water treatment method, so boiling water for 5 h is not cost-effective in terms of energy consumption. Since the last decade, there has been an increasing trend of HWTDs used by Iranian citizens, especially in semi-arid regions such as the south or center of the country. In addition, in most cities with or without water shortages, wealthy people use HWTDs in their homes. The hardness of drinking water as one of the important aspects of quality and its relationship with cardiovascular disease and mortality in different countries has been studied in recent years. Using HWTDs can have a high percentage of descaling. In other words, it can act as a good barrier for soluble solids and microbiological agents. As shown in Table 1, the HWTDs has a water hardness of 52.46 ± 0.14. The water coming out of the device is in the soft and very soft water group. In contrast, the boiling process reduced the amount of hardness to its normal level. Although the HWTDs were more efficient at removing water hardness, this method has two main problems. In the first case, the treatment unit discarded a significant amount of raw water (up to 75), which can be considered an important aspect due to the region's climate and water shortage [20–23]. On the other hand, all water-soluble solids, including minerals such as calcium, magnesium, and other essential elements, are taken, so consuming soft water can lead to long-term side effects [24]. In addition, the sudden release of highly soluble solids into the environment is also a significant problem. Conditions such as the age of filters and different levels of raw water quality or operating pressure also affect water output quality from home purifiers. Other parameters investigated in this study were electrical conductivity and the amount of calcium and magnesium ions [25]. The results showed that the home purifier significantly reduced the amount of calcium and magnesium in the water, and the amount of electrical conductivity was also changed due to the imbalance of water cations and anions. In the study of Fahiminia et al. [16], on the evaluation of point-of-use drinking water treatment systems has been reported that the HWTDs were able to reduce the dissolved solids content by more than 90% and produced soft water. Also, in the Jafaripour et al. [26] study, the result showed, RO techniques are able to reduce the hardness and fluoride levels in treated water that could be undesirable. Mara et al. [27] show that RO technique can transform very hard water into very soft water. According to published sources, recorded and

Table 1
The effect of refining processes on the physicochemical quality of water

Parameter	Boiling		HWTDs	Control	WHO	National Standard
	5 min	5 h				
Turbidity (NTU)	0.31 ± 0.051	0.19 ± 0.025	0.3 ± 0.063	0.34 ± 0.017	5	5
Conductivity (μS/cm)	709 ± 0.87	613 ± 0.85	539 ± 0.56	720 ± 0.69	–	–
Nitrate (mg/L)	8.29 ± 0.19	9.53 ± 0.14	7.43 ± 0.52	8.95 ± 0.35	50	50
Nitrite (mg/L)	0.01 ± 0	0.01 ± 0	Nd	0.8 ± 0.013	3	3
Chloride (mg/L)	45.9 ± 0.87	41.1 ± 0.25	40.8 ± 0.38	49.6 ± 0.15	250	400
Phosphate (mg/L)	0.005 ± 0	Nd	0.004 ± 0	0.01 ± 0.0005	0.2	0.2
Fluoride (mg/L)	0.56 ± 0.051	0.3 ± 0.011	Nd	0.96 ± 0.045	1.5	1.5
Total alkalinity (mg/L)	102 ± 0.98	43 ± 0.62	156 ± 0.91	167 ± 1.2	500	–
Calcium (mg/L)	68 ± 0.34	37.6 ± 0.15	14.4 ± 0.12	72.8 ± 0.21	200	200
Magnesium (mg/L)	23.9 ± 0.56	19.2 ± 0.18	25.85 ± 0.49	42.93 ± 0.17	150	150
Total hardness (mg/L)	148.3 ± 0.53	124.4 ± 0.97	52.46 ± 0.14	203.7 ± 0.68	100	500

Nd: Not detected

epidemiological studies have reported that consumption of water with low content of TDS and minerals can lead to adverse effects on the intestinal mucosa, impaired blood production and other body functions, reduced calcium and magnesium absorption. The World Health Organization states that calcium and potassium are two nutrients significantly found in drinking water. Magnesium is a trace element that plays a vital role in heart health. Calcium is also very effective in bone health, so its presence in drinking water and daily intake by consumers will play an important role in humans' health, which should also be considered [28]. Therefore, given the above facts about soft water consumption and the nutritional value of elements such as Ca and Mg, and the role of drinking water in providing parts of the required nutrients, similar adverse health effects are expected in the long run [29]. The fluoride concentration in the control sample was about 0.96, which reached undetectable values of 0.3 and 0.56 due to HWTDs, boiling for 5 h and 5 min processes, respectively. One reason for solutes' reduction in-home purifiers is that these devices removed all cations and anions regardless of whether they were useful or not, and there is no selective removal in these devices [30]. Therefore, one of the disadvantages of selective desalination of these devices is reducing fluoride concentration to below the appropriate level. Proper fluoride concentration in drinking water is important for dental health because the role of fluoride in the growth and strength of teeth and bones, especially in growing children, has been proven, and one of the ways that fluoride enters the body is through drinking water consumption [31–33]. Examining nitrate and residual nitrite from all three treatment processes highlights a significant point. Although the amount of nitrate decreased by all three processes, it increased in boiling for a long time. A review of the previous studies shows that no similar work has been done so far, and more research and experiments are required in this field. However, it can be suggested not to boil water for a long time and be careful when consuming re-boiled water. Besides, chloride and phosphate are other minerals in water that have been reduced in varying amounts by the processes used. One of the main challenges in using surface water resources is the high concentration of natural organic matter leading to the formation of trihalomethanes, which is associated with carcinogenic risks and destructive effects on the respiratory system of humans and animals [34–36]. Hence, removing these harmful compounds from drinking water is vital to maintain consumers' health [37]. This study showed that the water boiling process for 5 min and 5 h could significantly reduce the amount of THMs, (P-value < 0.05), but no significant difference was observed in different periods (Fig. 2).

Also, HWTDs can reduce the amount of the pollutant properly (P-value < 0.05). The THMs that are most common in drinking water are chloroform ($CHCl_3$), bromodichloromethane, or dichlorobromomethane ($CHBr_2Cl$), dibromochloromethane or chlorodibromomethane ($CHCLBr_2$), and bromoform ($CHBr_3$), and the values of each are listed separately in Table 2.

4. Conclusion

Since various water purifiers are very popular nowadays, we examined the efficiency of a sample of these devices on the physicochemical quality of water in this study. The effect of heating at different times on drinking water quality was also investigated. One of the remarkable achievements of this study is that HWTDs can have a significant effect on the removal of undesirable water factors, but in contrast, many useful salts will be removed by this method. Therefore, this method is not recommended except in areas where drinking water is salty. The study also found that prolonged boiling increases the amount of nitrite in water, which can be dangerous to health. As this issue has not yet been explored, it could be a

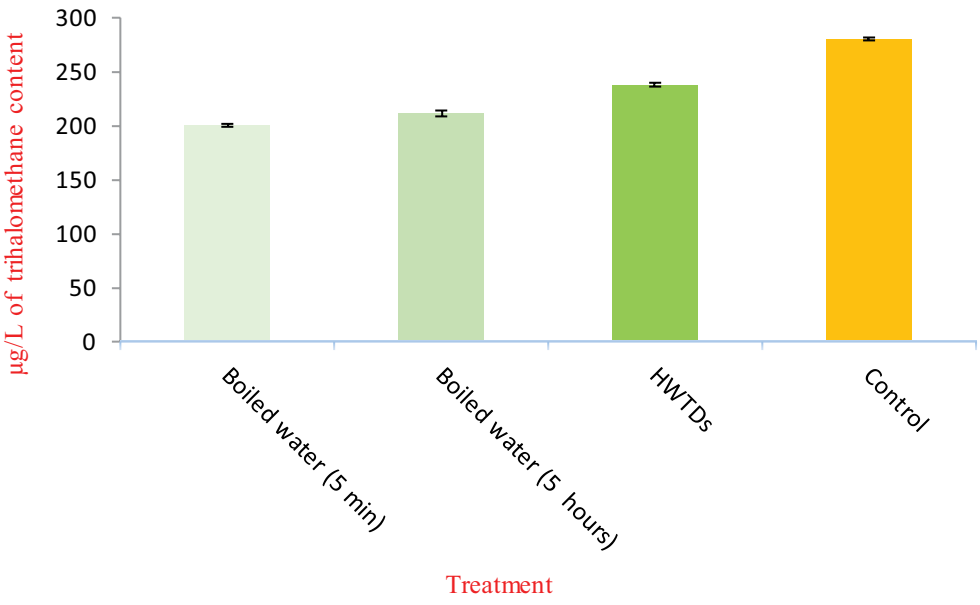

Fig. 2. The effect of refining processes on the trihalomethane content of water.

Table 2
The effect of refining processes on the other halomethanes compound in water

Treatment processes	Chloroform (μg/L)	Dichlorobromomethane (μg/L)	Dibromochloromethane (μg/L)	Bromoform (μg/L)
Boiled water (5 h)	Nd	Nd	Nd	Nd
Boiled water (5 min)	Nd	Nd	5.07 ± 0.087	3.14 ± 0.05
HWTDs	Nd	6.92 ± 0.012	10.12 ± 0.165	9.29 ± 0.45
Control	12.12 ± 0.187	17.18 ± 0.14	23.63 ± 0.98	24.87 ± 0.87
Permissible limit (EPA)	300	100	100	100

Nd: Not detected

frontrunner for future studies. Therefore, according to the data obtained from this study, one should be careful in the frequent and long-term use of water purifiers, and it can be suggested that the best and the easiest way to purify drinking water in areas that do not have access to safe water is to boil water for a short time.

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References

[1] H. Atabati, H. Kassiri, E. Shamloo, M. Akbari, A. Atamaleki, F. Sahlabadi, N.T.T. Linh, A. Rostami, Y. Fakhri, A. Mousavi Khaneghah, The association between the lack of safe drinking water and sanitation facilities with intestinal *Entamoeba* spp. infection risk: a systematic review and meta-analysis, Plos One, 15 (2020) 1–17.
[2] A. Salari, S. Khanzadi, Z. Rezaei, Survey of fluoride, chlorine, potassium, sodium, and trihalomethane contents in the drinking water of five major universities in Iran, J. Adv. Environ. Health Res., 6 (2018) 202–209.
[3] M. Qasemi, M. Afsharnia, M. Farhang, M. Ghaderpoori, A. Karimi, H. Abbasi, A. Zarei, Spatial distribution of fluoride and nitrate in groundwater and its associated human health risk assessment in residents living in Western Khorasan Razavi, Iran, Desal. Water Treat., 170 (2019) 176–186.
[4] E. Ramirez, E. Robles, M.E. Gonzalez, M.E. Martinez, Microbiological and physicochemical quality of well water used as a source of public supply, Air Soil Water Res., 3 (2010) 105–112.
[5] A. Mohseni-Bandpi, D.J. Elliott, M.A. Zazouli, Biological nitrate removal processes from drinking water supply-a review, J. Environ. Health Sci. Eng., 11 (2013) 1–11, doi: 10.1186/2052-336X-11-35.
[6] A. Salari, S. Khanzadi, Z. Rezaei, Nitrate and nitrite concentration in the drinking water of some universities in Iran, J. Nutr. Fast. Health, 8 (2020) 141–144.
[7] M. Qasemi, M. Farhang, M. Morovati, M. Mahmoudi, S. Ebrahimi, A. Abedi, J. Bagheri, A. Zarei, J. Bazeli, M. Afsharnia, S. Ghalehaskar, A. Ghaderpoury, Investigation of potential human health risks from fluoride and nitrate via water consumption in Sabzevar, Iran, Int. J. Environ. Anal. Chem., 102 (2022) 307–318.
[8] Y. Wang, R. Yu, G. Zhu, Evaluation of physicochemical characteristics in drinking water sources emphasized on fluoride: a case study of Yancheng, China, Int. J. Environ. Res. Public Health, 16 (2019) 1030, doi: 10.3390/ijerph16061030.
[9] A. Asadullah, K. Nisa, S. Ismat Khan, Physico-chemical properties of drinking water available in educational institutes of Karachi city, Sci. Technol. Dev., 32 (2013) 28–33.
[10] A. Fadaei, M. Sadeghi, Evaluation and assessment of drinking water quality in Shahrekord, Iran, Resour. Environ., 4 (2014) 168–172.
[11] M. Tadesse, D. Tsegaye, G. Girma, Assessment of the level of some physico-chemical parameters and heavy metals of Rebu river in oromia region, Ethiopia, MOJ Biol. Med., 3 (2018) 99–118.
[12] N. Thiriat, H. Paulus, B. Le Bot, P. Glorennec, Exposure to inhaled THM: comparison of continuous and event-specific exposure assessment for epidemiologic purposes, Environ. Int., 35 (2009) 1086–1089.
[13] J.L.P. Pavón, S.H. Martín, C.G. Pinto, B.M. Cordero, Determination of trihalomethanes in water samples: a review, Anal. Chim. Acta, 629 (2008) 6–23.
[14] S. Pan, W. An, H. Li, M. Su, J. Zhang, M. Yang, Cancer risk assessment on trihalomethanes and haloacetic acids in drinking water of China using disability-adjusted life years, J. Hazard. Mater., 280 (2014) 288–294.
[15] D.A. Shigut, G. Liknew, D.D. Irge, T. Ahmad, Assessment of physico-chemical quality of borehole and spring water sources supplied to Robe Town, Oromia region, Ethiopia, Appl. Water Sci., 7 (2017) 155–164.
[16] M. Fahiminia, M. Mosaferi, R.A. Taadi, M. Pourakbar, Evaluation of point-of-use drinking water treatment systems' performance and problems, Desal. Water Treat., 52 (2014) 1855–1864.
[17] M.D. Sobsey, C.E. Stauber, L.M. Casanova, J.M. Brown, M.A. Elliott, Point of use household drinking water filtration: a practical, effective solution for providing sustained access to safe drinking water in the developing world, Environ. Sci. Technol., 42 (2008) 4261–4267.
[18] G.-T. Chae, S.-T. Yun, B. Mayer, K.-H. Kim, S.-Y. Kim, J.-S. Kwon, K. Kim, Y.-K. Koh, Fluorine geochemistry in bedrock groundwater of South Korea, Sci. Total Environ., 385 (2007) 272–283.
[19] P.-C. Chiang, E.-E. Chang, P.-C. Chang, C.-P. Huang, Effects of pre-ozonation on the removal of THM precursors by coagulation, Sci. Total Environ., 407 (2009) 5735–5742.
[20] J.K. Mwabi, F.E. Adeyemo, T.O. Mahlangu, B.B. Mamba, B.M. Brouckaert, C.D. Swartz, G. Offringa, L. Mpenyana-Monyatsi, M.N.B. Momba, Household water treatment systems: a solution to the production of safe drinking water by the low-income communities of Southern Africa, Phys. Chem. Earth, Parts A/B/C, 36 (2011) 1120–1128.
[21] C. Poulos, J.-C. Yang, S.R. Patil, S. Pattanayak, S. Wood, L. Goodyear, J.M. Gonzalez, Consumer preferences for household water treatment products in Andhra Pradesh, India, Soc. Sci. Med., 75 (2012) 738–746.
[22] P. Mukherjee, D. Chatterjee, J. Jana, P.B. Maity, A. Goswami, H. Saha, M. Sen, B. Nath, D. Shome, M. Joyti Sarkar, D. Bagchi, Household water treatment option: removal of arsenic in presence of natural Fe-containing groundwater by solar oxidation, Trace Met. Contam. Environ., 9 (2007) 603–622.

[23] Q. Mahmood, S.A. Baig, B. Nawab, M.N. Shafqat, A. Pervez, B.S. Zeb, Development of low cost household drinking water treatment system for the earthquake affected communities in Northern Pakistan, Desalination, 273 (2011) 316–320.
[24] N. Melián-Martel, J.J. Sadhwani Alonso, S.O. Pérez Báez, Reuse and management of brine in sustainable SWRO desalination plants, Desal. Water Treat., 51 (2013) 560–566.
[25] H. Elfil, A. Hamed, A. Hannachi, Technical evaluation of a small-scale reverse osmosis desalination unit for domestic water, Desalination, 203 (2007) 319–326.
[26] M. Jafaripour, M. Salimi Amrod, A. Ziaee Pour, R. Davoudi, Health, sanitary and economic evaluation of Home-like systems of water treatment (Reverse Osmosis, RO) in Qom city, J. Water Wastewater, 22 (2011) 15–21 (in Persian).
[27] D.D. Mara, Water, sanitation and hygiene for the health of developing nations, Public Health, 117 (2003) 452–456.
[28] R. Dehghanzadeh, N. Talebzadeh, H. Taghipour, H. Aslani, Evaluation impact of point of use (POU) household water treatment devices (HWTDs) application on tap water quality and determine the removal efficiency of THMs and HAAs, Desal. Water Treat., 105 (2018) 62–72.
[29] Y. Zhou, R.S.J. Tol, Implications of desalination for water resources in China—an economic perspective, Desalination, 164 (2004) 225–240.
[30] M. Nair, D. Kumar, Water desalination and challenges: The Middle East perspective: a review, Desal. Water Treat., 51 (2013) 2030–2040.
[31] WHO, Guidelines for Drinking-Water Quality, World Health Organization, 216 (2011) 303–304.
[32] R. Yao, F. Meng, L. Zhang, D. Ma, M. Wang, Defluoridation of water using neodymium-modified chitosan, J. Hazard. Mater., 165 (2009) 454–460.
[33] M. Ghaderpoori, G.R.J. Khaniki, M. Dehghani, M. Shams, A. Zarei, Determination of fluoride in bottled water sold in Tehran market, Iran, Am.-Eurasian J. Agric. Environ. Sci., 6 (2009) 324–327.
[34] J. Zhang, J. Yu, W. An, J. Liu, Y. Wang, Y. Chen, J. Tai, M. Yang, Characterization of disinfection byproduct formation potential in 13 source waters in China, J. Environ. Sci., 23 (2011) 183–188.
[35] H. Zhang, Y. Zhang, Q. Shi, J. Hu, M. Chu, J. Yu, M. Yang, Study on transformation of natural organic matter in source water during chlorination and its chlorinated products using ultrahigh resolution mass spectrometry, Environ. Sci. Technol., 46 (2012) 4396–4402.
[36] F.C. Kent, K.R. Montreuil, A.K. Stoddart, V.A. Reed, G.A. Gagnon, Combined use of resin fractionation and high performance size exclusion chromatography for characterization of natural organic matter, J. Environ. Sci. Health, Part A, 49 (2014) 1615–1622.
[37] A.D. Knowles, J. MacKay, G.A. Gagnon, Pairing a pilot plant to a direct filtration water treatment plant, Can. J. Civ. Eng., 39 (2012) 689–700.