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Assessment of household reverse-osmosis systems in heavy metal and solute ion removal in real and synthetic samples

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Original Article

Abstract

In this study, the efficiency of household reverse-osmosis system (HROS) with and without neutralizer accessory was investigated in both real and synthetic samples. The real samples were collected from rural and urban public drinking-water systems with and without primary refinery treatment. The selected areas were situated in the Kurdistan province, Iran. The HROS model RO100GPD with and without neutralizer accessory was used in all experiments to prevent effects of the membrane used, age of devices, and length of time in service. In order to assess sample quality, some more common physico-chemical analyses consisting of hardness, Ca^{2+}, Mg^{2+}, total dissolved solids (TDS), electrical conductivity (EC), alkalinity, Cl^-, Br^-, SO_4^{2-}, PO_4^{3-}, NO_3^-, NO_2^-, and heavy metals were performed based on standard methods. The results indicate that HROS and neutralizer accessory have significant effects on the physico-chemical properties of feed water. However, the results indicate the instability of HROS output water quality, but they verify that this instability cannot reduce the output quality. Finally, results emphasize that HROS output water meets standard levels regardless of the input water quality and application of neutralizer accessory.

KEYWORDS: Membranes, Drinking Water, Heavy Metals, Solute Ion, Hardness, Water Quality, Iran

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Introduction

The Iranian National Drinking Water Standards and other international standard systems specify a maximum contaminant level (MCL) and a maximum desirable level (MDL) for a number of chemical species, including anions, cations especially heavy metals, and some organic compounds [1]. The MCLs are specified to minimize potential health effects arising from the ingestion of these species in drinking water.[2]. For instance, high levels of nitrite and nitrate can cause Methemoglobinemia, which can be fatal to infants. Moreover, the MDLs are specified to maximize quality and desirability arising from the ingestion of these species in drinking water.[3]

Public drinking-water systems and local aquifers in Iran produce different drinking water regarding their quality. Sometimes concentrations of arsenic, nitrate, and hardness are not at the standard levels for drinking water, or the supplied water has an unpleasant smell or taste. Household reverse-osmosis systems (HROS) are efficient, economic, and simple to install or maintain. The application of HROS in Iran has promptly increased especially in areas that water is not supplied by public drinking-water systems or the supplied water does not meet standard level or satisfy the customers. [4,5]

In HROS, water is forced to pass through membranes with angstrom size pores. The solutes

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in the feed water are rejected by the membrane, and thus, the treated water contains lower concentrations of solute than feed water. It has been reported that the efficiency of HROS in removing contaminants and other chemical species varies with the specific specie, membrane used, age of devices, and length of time in service. However, the effects of physico-chemical properties of feed water on the HROS efficiency have not been fully investigated. The size and selectivity of RO membranes and other membranes that operate based on size are illustrated in figure 1.[6-9]

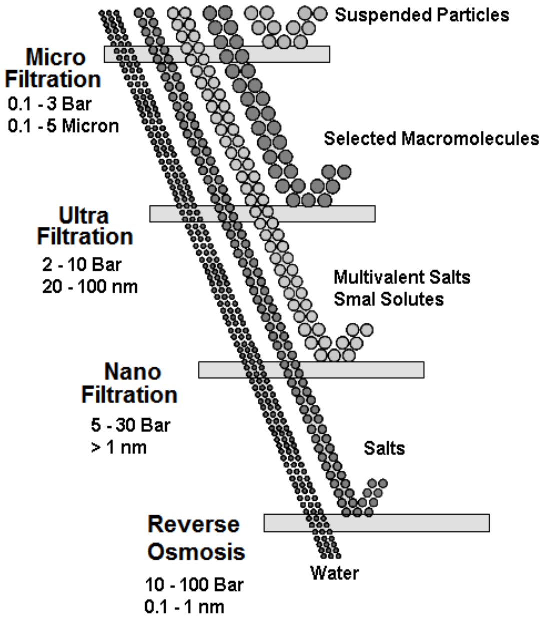

Figure 1. Reverse-osmosis membrane size and its selectivity rather than other membrane work with size

Improvements in taste of drinking water and promising results of simple tests, like conductivity, are misleading in the evaluation of HROS. Therefore, because water treated by HROS has recently become a significant part of the water consumed by the public, it has been urged to precisely investigate these systems.[6,10-12]

Extremely low concentrations of total dissolved solids (TDS) result in undesirable drinking water with flat and insipid taste. Therefore, an optional neutralizer accessory has been presented as a solution by the companies to replace minerals and to give it a taste of spring water. Albeit it is essential to evaluate this new accessory, no study has been reported yet.

Finally, the purposes of this study were first, evaluation of HROS output water quality, second, investigation of HROS influences on feed water, and third, evaluation of the neutralizer accessory and its influences and urgency.

Materials and Methods

The Kurdistan province of Iran was selected as the study area (Figure 2). In addition, 2 urban drinking water samples were collected from Sanandaj and Sarvabad, Iran, and 3 rural drinking water samples were collected from Daraki (Sarvabad, Kurdistan, Iran), Goor-Baba-Ali (Divandare, Kurdistan Iran), and Gharakhlar (Bijar, Kurdistan, Iran). This area was selected due to availability and low quality of supplied water in this area. High levels of nitrate, arsenic, and hardness were reported for drinking water in this area. All samples were ground water without any further treatment, except the Sanandaj sample that was treated in the refinery unit of Sanandaj. In addition to the real samples, 1 synthetic sample containing common heavy metals of drinking water in Iran was prepared to investigate the heavy metal removal efficiency of HROS.

Samples were collected based on standard methods of water and wastewater examination (No. 1060) using 3 heavy polyethylene containers. The 3 samples consisted of 20 liters sample as feed water of HROS, 2 liters sample for heavy metal analysis with 1% acid nitric addition, and 2 liters sample for other physico-chemical analysis. All containers were kept sealed and refrigerated at 5 °C until the time of analysis.

The HROS model RO100GPD (Luna Water Co., Canada) with and without neutralizer accessory was used in this study. In addition to neutralizer accessory, RO100GPD contains five filters containing 25 microns sediment pre-filter, 10 microns active carbon, and 1 micron sediment pre-filter and osmosis membrane. In the filtration

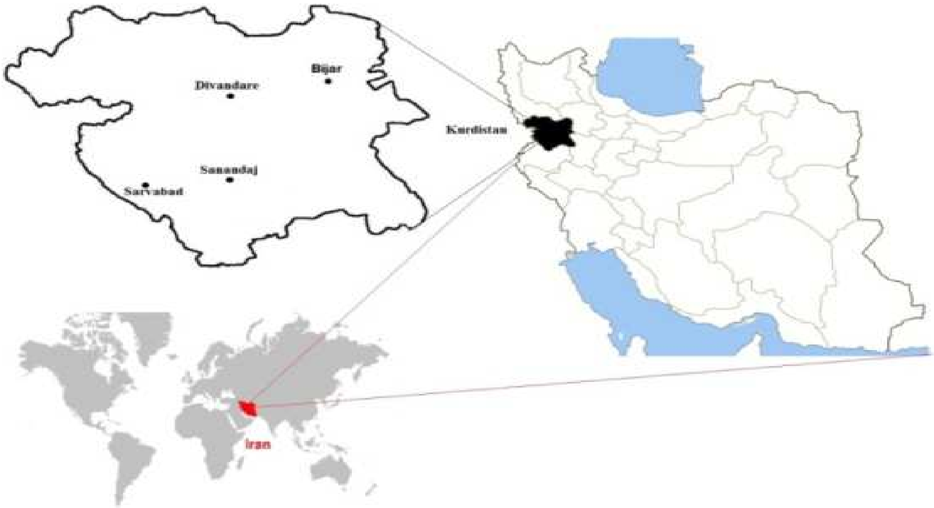

Figure 2. Study area (Kurdistan province, Iran)

stage, feed water first passes through sediment filters using a primary pomp where silt, sediment, sand, and clay particles are removed. Water is then forced through a high efficiency carbon block filter where micro-pulverized carbon efficiently adsorbs chlorine, chloramines, pesticides, and other harmful organic chemicals and pollutants. Then, pre-filtered feed water stripped of membrane-damaging particles and chemicals flows into the RO membrane module using a 6 bar (85 psi) secondary pump where pure water molecules are forced through the RO membrane leaving salts, metals, and other impurities to be flushed from the system. Reverse-osmosis membranes, although very efficient in removing contaminants, still allow trace amounts to pass through. Nitrates, phosphates, and silica are among the substances not fully removed.

The common physico-chemical analyses consisting of anions, heavy metals, hardness, calcium, magnesium, alkalinity, TDS, and electrical conductivity (EC) were performed based on standard methods.[13] Phosphate, nitrate, nitrite, chloride, bromide, and sulfate levels were determined by standard ion chromatography method. Heavy metals analysis was determined by standard inductively coupled plasma (ICP) method.

Ion chromatography was carried out based on the United States Environmental Protection Agency (EPA) method 300.0 using 882 compact IC plus (Metrohm, Switzerland) equipped with a conductivity detector and a 20 µl injection loop. Separation of anions was carried out on a Metrosep A Supp 4-250 analytical column at 25 °C with a 1 ml/min flow rate of eluent. Metrosep A Supp 4.5 Guard column and suppressor systems were also connected to the analytical columns. A mixture of sodium hydrogen carbonate (1.7 mm) and sodium carbonate (1.8 mm) was used as the mobile phase for eluting anions. Data acquisition and instrument settings were performed by Magic Net software (version 2.1; Metrohm, Switzerland). The ultra-pure water type 1 was used as blank. Mixed standard solutions were used to plot the calibration curve with appropriate concentrations of each desired anions. The linear relationship between peak area and concentration were confirmed experimentally.

Determination of the heavy metals was achieved by ICP-OES (model Spectro arcos., SPECTRO Inc., Germany). The main operation parameters were torch type (flared end EOS Torch 2.5 mm), detector type (CCD), nebulizer type (cross flow), nebulizer flow (0.85 l/min), plasma power (1400 W), coolant flow (14.5 l/min) and pump rate (30 RPM). The ultra-pure water type 1 was used as blank. Mixed standard solutions were used to plot the calibration curve with appropriate concentrations of each desired heavy metal. The linear relationship between peak area and concentration were confirmed experimentally.

Results and Discussion

In each sample, the mentioned physico-chemical tests were performed for both feed and output sample water. The experimentally obtained data are summarized in table 1 and figure 3. The Iranian National Drinking Water Standards' levels [maximum acceptable concentration (MAC), and maximum desirable concentrations (MDC)] were presented for each parameter in the same table along with the experimental data.

The HROS influences

The results clearly show the influences of HROS on the feed water. As presented in table 1 and figure 3, the concentrations of species were affected by HROS for all investigated parameters. The paired t-test analysis also confirmed the significant influences of HROS (Table 1).

Table 1. Experimental and standard values of investigated physico-chemical parameters

Sample	TDS (mg/l)	Hardness (mg/l)	Ca^{2+} Hardness (mg/l)	Mg^{2+} Hardness (mg/l)	HCO_3^- Alkalinity (mg/l)	SO_4^- (ppm)	NO_3^- (ppm)	Cl^- (ppm)	As (ppb)	Cu (ppb)	Pb (ppb)
MDC	1000	200	-	-	-	250.0	-	250.0	-	1000	-
MAC	1500	500	300	30	-	400.0	50.0	400.0	10	2000	10
Daraki*	222	220	200	20	196	10.6	5.6	8.2	< 1.2	22	3
Daraki**	171	20	12	8	26	2.1	0.4	1.3	< 1.2	5	2
Exclusion (%)	23	91	94	60	87	80.0	93.0	84.0	-	77	33
GoorBabaAli*	454	400	280	120	336	52.0	5.5	28.7	68.0	3	2
GoorBabaAli**	26.6	68	36	32	30	2.8	0.4	1.4	< 1.2	< 0.3	1
Exclusion (%)	94	83	87	73	91	95.0	92.0	95.0	> 98	> 90	50
Gharakhlar*	305	232	180	52	222	55.0	14.9	11.6	< 1.2	3	2
Gharakhlar**	61	44	28	16	48	9.8	1.1	3.0	< 1.2	< 0.3	1
Exclusion (%)	80	81	84	69	78	82.0	93.0	74.0	0	> 90	50
Sarvabad*	371	348	260	88	286	29.0	16.2	13.8	< 1.2	< 0.3	2
Sarvabad$_o$	328	320	232	88	272	27.7	10.9	12.7	< 1.2	< 0.3	1
Exclusion (%)	12	8	11	0	5	4.0	33.0	8	-	-	50
Sarvabad*	332	322	242	80	286	-	-	-	-	-	-
Sarvabad**	244	208	180	28	210	-	-	-	-	-	-
Exclusion (%)	27	35	26	65	27	-	-	-	-	-	-
Sanandaj*	196	180	140	40	168	22.5	3.4	10.8	< 1.2	1	4
Sanandaj**	155	160	104	18	116	16.1	1.5	8.4	< 1.2	< 0.3	2
Exclusion (%)	21	11	26	55	31	28.0	56.0	22.0	-	> 70	50
Sanandaj*	177	175	140	35	164	-	-	-	-	-	-
Sanandaj**	99	64	48	16	80	-	-	-	-	-	-
Exclusion (%)	44	63	66	54	51	-	-	-	-	-	-
Sanandaj*	177	175	140	35	164	-	-	-	-	-	-
Sanadaj**,***	159	104	72	32	130	-	-	-	-	-	-
Exclusion (%)	10	41	49	9	21	-	-	-	-	-	-
Synthetic*	-	-	-	-	-	-	-	-	24	52	34
Synthetico	-	-	-	-	-	-	-	-	< 1.2	< 0.3	2
Exclusion (%)	-	-	-	-	-	-	-	-	95	99	94
T-test objects	P of T-test results										
T-test (t_1)	< 0.001	0.09	-	-	-	< 0.001	-	< 0.001	-	-	-
T-test (t_2)	< 0.001	< 0.001	0.01	0.05	-	< 0.001	< 0.001	< 0.001	-	-	-
T-test (t_3)	< 0.001	0.12	-	-	-	< 0.001	-	< 0.001	-	-	-
T-test (t_4)	< 0.001	< 0.001	< 0.001	0.96	-	< 0.001	< 0.001	< 0.001	-	-	-
T-test (t_5)	0.04	0.01	0.01	0.03	0.02	0.10	0.03	0.12	-	-	-

MAC: maximum acceptable concentration; MDC: maximum desirable concentrations; *Feed water; **Output water; ***Optional neutralizer accessory was installed; t_1: comparison of feed water and MDC; t_2: comparison of output water and MAC; t_3: comparison of output water and MDC values; t_1: comparison of output water and MAC; t_5: comparison of feed water and output water

Quality evaluation of output water

The comparison between the Iranian National Drinking Water Standards (MAC and MDC) and experimental data for feed and output water clearly illustrate that the HROS output water meets both MAC and MDC standards regardless of feed water quality. The one-sample t-test was applied to evaluate the difference between experimental data and MAC/MDC (Table 1).

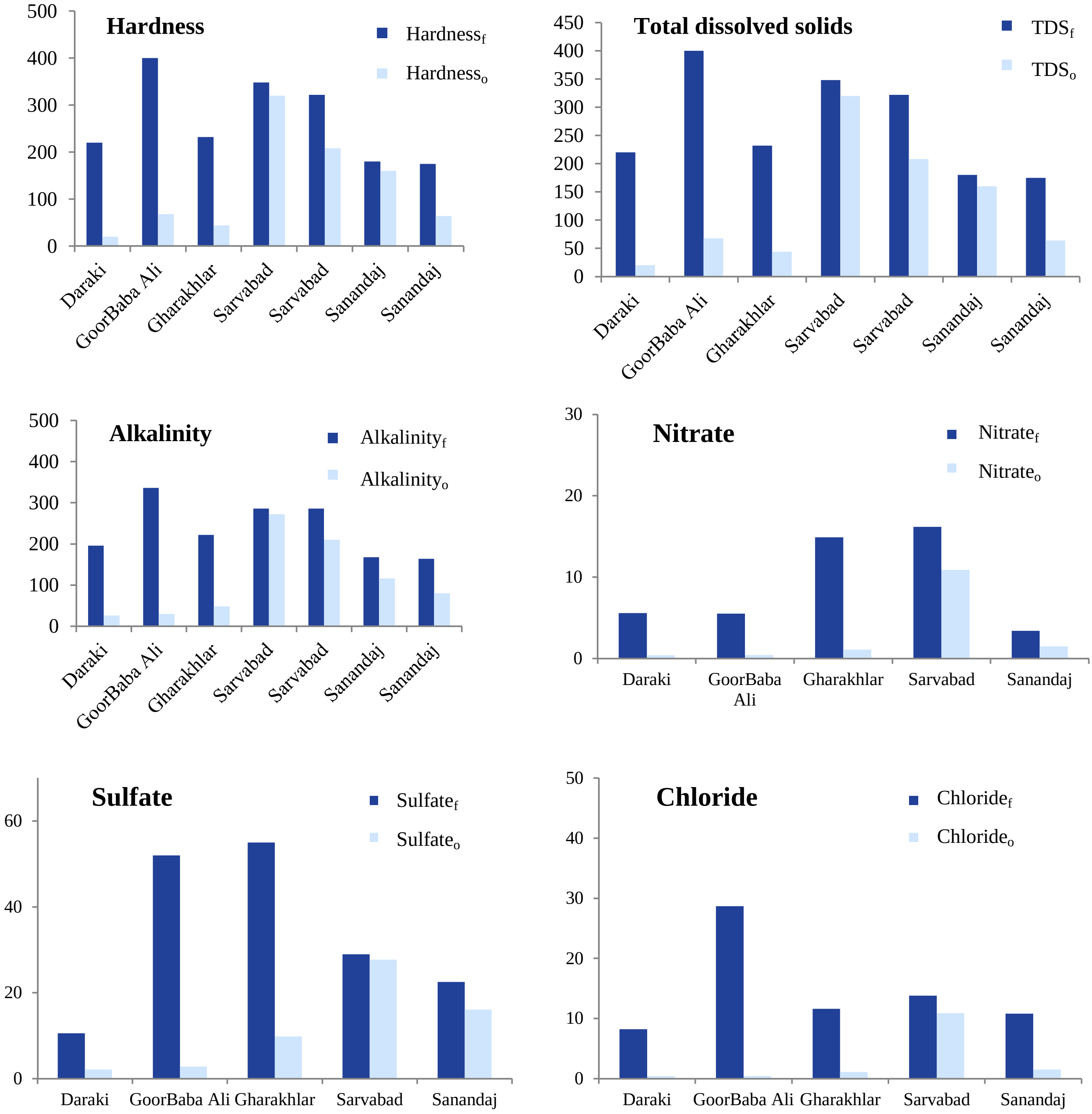

Figure 3. Physico-chemical compression for whole investigated species in feed and output water quality

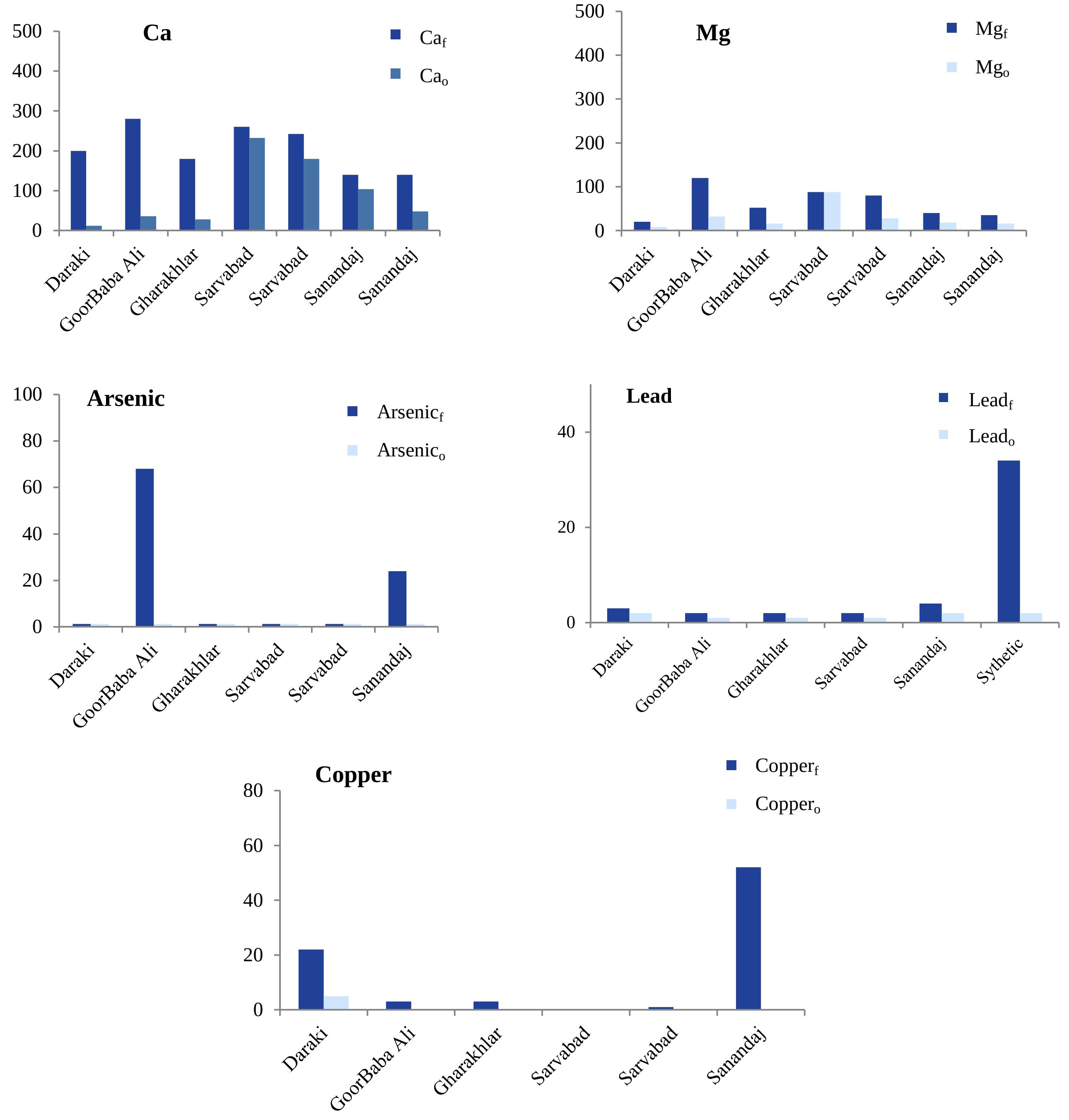

Figure 3. Physico-chemical compression for whole investigated species in feed and output water quality (Continue)

The stability evaluation of HROS output

The results of two repeated experiments for Sanandaj and Sarvabad were presented in table 1 and figure 4. The results clearly demonstrate that although the output water in both cases was lower than standard levels, there are significant differences between outputs. Similar differences cannot be seen for feed water. Then, it can be said that HROS cannot produce stable and repeatable output, but it can produce standard output.

Investigation of neutralizer accessory influences

Evaluation of neutralizer accessory results was presented at figure 5 and table 1. However neutralizer accessory affects the output, but this influences is not urgent. On the other hand, the compensation of TDS as a most important duty of this accessory was occurred when increasing of TDS more than 100 mg/l prevents the flat, insipid taste of output water.

Finally, paired t-test was applied for statistical evaluation of differences between the HROS output with and without installing neutralizer accessory, and differences between the repeated input/output samples (Table 2). The statistical evaluation confirmed the presented discussion.

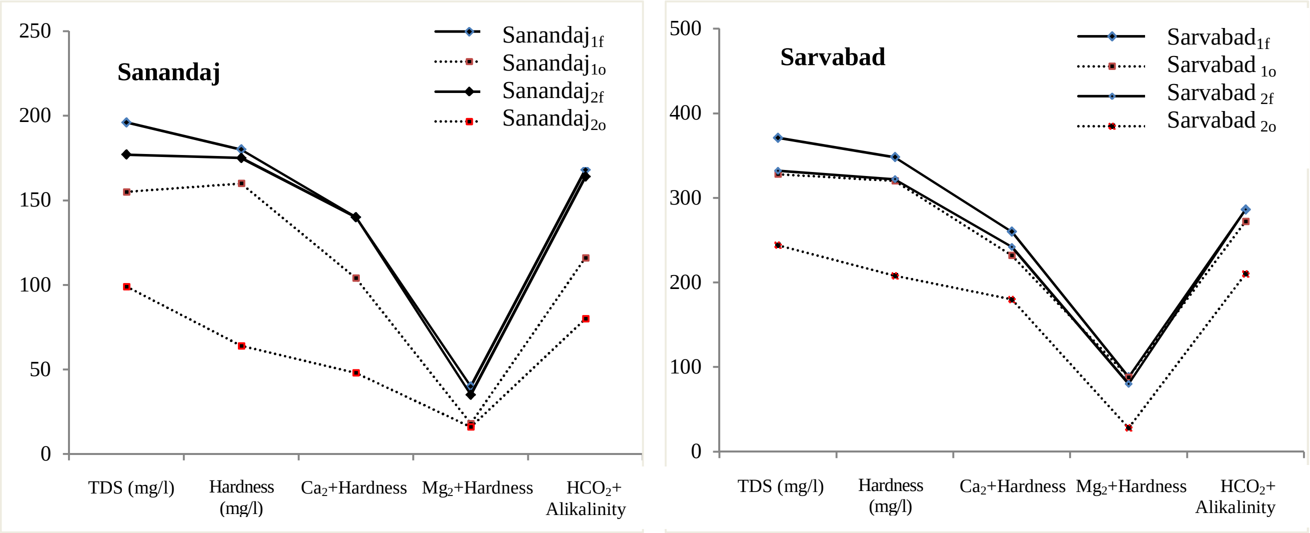

Figure 4. Repeated samples of Sanandaj and Sarvabad
TDS: Total dissolved solids

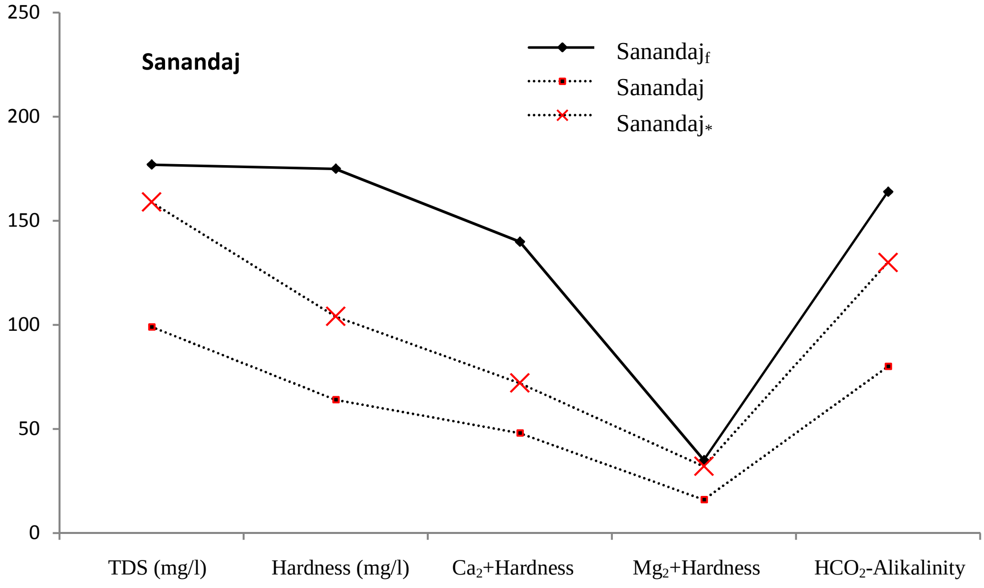

Figure 5. Neutralizer accessory efficiency
TDS: Total dissolved solids

Table 2. T-test results for evaluation of neutralizer accessory and repeated samples

T-test objects	P
T-test for HROS output with and without neutralizer accessory	0.010
T-test for repeated output of Sanandaj	0.030
T-test for repeated feed HROS samples for Sanandaj	0.110
T-test for repeated output of Sarvabad	< 0.001
T-test for repeated feed HROS samples for Sarvabad	0.060

HROS: Household reverse-osmosis system

Conclusion

In this study, the influences of household HROS on feed water, quality of output water of HROS regarding standard MAC and MDC levels, influences of the new neutralizer accessory, and the stability (repeatability) of physico-chemical characteristics of the output water were investigated. Several rural and urban samples with different initial physico-chemical characteristics were used as feed water. It can be concluding from the results that the output water is different from the feed water. This means that these systems strongly influence the feed water. Moreover, the results show that the output water meets the standard levels of MAC and even MDC completely regardless of feed water quality. Based on the results, however, the output water did not show suitable repeatability, but output water was always of standard quality. Thus, it can be concluded that, for both polluted and standard feed water, application of HROS results in high quality output water regarding the investigated physico-chemical properties, but it is more urgent and applicable for polluted feed water specially feed water containing heavy metal pollutants. Although the new neutralizer accessory influences the output water significantly, it is not a necessity for HROS because the output of this system is not pure water and contains a suitable amount of TDS. This means that the membranes used in these systems are not reverse-osmosis membranes and are probably nano-filters. The acceptable TDS and hardness levels of the output water are clear evidences for the use of nanofilters instead of reverse-osmosis systems. This neutralizer accessory may be more applicable to real reverse-osmosis membrane-based systems.

Conflict of Interests

Authors have no conflict of interests.

Acknowledgements

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References

1. Jackson PE. Determination of inorganic ions in drinking water by ion chromatography. TrAC Trends in Analytical Chemistry 2001; 20(6-7): 320-9.
2. Environmental Protection Agency. Announcement of Public Meeting on the Consumer Confidence Report (CCR) Rule Retrospective Review [Online]. [cited 2012]; Available from: URL: https://www.federalregister.gov/articles/2012/02/03/2012-2025/announcement-of-public-meeting-on-the-consumer-confidence-report-ccr-rule-retrospective-review
3. Choi JS, Lee S, Kim JM, Choi S. Small-scale desalination plants in Korea: Technical challenges. Desalination 2009; 247(1-3): 222-32.
4. Robbins A. Reverse osmosis purification system [Online]. [cited 2001]; available from: URL: http://www.google.com/patents/US6190558
5. Mora HF, O'Hare RJ. Compact reverse osmosis system with cold water flush [Online]. [cited 1991]; Available from: URL: http://www.google.com/patents/US5122265
6. Walker M, Seiler RL, Meinert M. Effectiveness of household reverse-osmosis systems in a Western U.S. region with high arsenic in groundwater. Sci Total Environ 2008; 389(2-3): 245-52.
7. Mosaferi M, Yunesian M, Mesdaghinia A, Nadim A, Nasseri S, Mahvi AH. Arsenic Occurrence in Drinking Water of I.R of Iran: The Case of Kurdistan Province.

Fate of arsenic in the environment Dhaka: BUET-UNU International Symposium, International Training Network Centre, Bangladesh University of Engineering and Technology, United Nations University, Tokyo 2003; 1-6.

8. Sharifi Z, Safari Sinegani AA. Arsenic and Other Irrigation Water Quality Indicators of Groundwater in an Agricultural Area of Qorveh Plain, Kurdistan, Iran. American-Eurasian J Agric Environ Sci 2012; 12(4): 548-55.
9. Manjikian S. Reverse osmosis water purifying system for household use [Online]. [cited 1974]; Available from: URL: http://www.google.com/patents/US3849305
10. Saad B, Pok FW, Ahmad Sujari AN, Idiris Saleh M. Analysis of anions and cations in drinking water samples by Capillary Ion Analysis. Food Chemistry 1998; 61(1-2): 249-54.
11. Mahmood Q, Baig SA, Nawab B, Shafqat MN, Pervez A, Zeb BS. Development of low cost household drinking water treatment system for the earthquake affected communities in Northern Pakistan. Desalination 2011; 273(2-3): 316-20.
12. Lashkaripour GR, Zivdar M. Desalination of brackish groundwater in Zahedan city in Iran. Desalination 2005; 177(1): 1-5.
13. American Public Health Association, American Water Works Association, Water Pollution Control Federation, Water Environment Federation. Standard Methods for the Examination of Water and Wastewater. Washington, DC: American Public Health Association; 1915.