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A study on quantitative and qualitative characteristics of water obtained from the air conditioning systems

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ABSTRACT

As the city of Kashan is located in an arid area in Iran and is facing a severe water crisis, condensate water recovered from air conditioners could be considered a potential water source. The study aimed to evaluate this water source in terms of its quantity and physical and chemical characteristics. A total of 72 condensate water samples were collected from air-conditioners during three months in summer 2021. The samples were tested for pH, electrical conductivity, turbidity, total hardness, total dissolved solids, alkalinity, nitrate, chloride, CO_2, Pb, Zn, Cd, and As. It was found that each device produced on average of 0.83 liters of water an hour. The physical and chemical characteristics of the water meet the World Health Organization and Iranian Standards for drinking water except for heavy metals concentration. Finally, it is concluded that the water quality is appropriate for a variety of non-drinking purposes and, due to the significant volume, the decision to utilize such a large volume of water is economically sensible. However, due to the presence of heavy metals in the recovered water, human and environmental health criteria must be taken into consideration.

Keywords: Air conditioning system; Human health; Water resources; Condensate water

1. Introduction

The oceans, seas and lakes contain almost 97.5% of the world's water as saline water and the remaining 2.5% is freshwater present in the glaciers, ice caps, snowy mountains, atmosphere, and groundwater. Of this 2.5%, a small amount is available to humans for daily water demands [1,2]. Furthermore, several issues such as climate change, progressive water shortages, population growth, and urbanization have posed challenges to water treatment systems. According to the World Health Organization (WHO), half of the world's population will be living in water-stressed areas by 2025 [3]. According to the United Nations, gastrointestinal diseases such as diarrhea account

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for nearly 80% of newborn mortality rates globally [4], and more than a third of deaths in developing nations are caused by contaminated drinking water [5,6]. Many studies have been conducted to evaluate the quality of drinking water [7–10]. On the other hand, freshwater shortages have risen across the world, particularly in arid regions [11,12]. As a result, a major concern of health officials is providing enough drinking water and assuring its safety [13,14]. Different technologies have been developed to produce freshwater, including the application of desalination plants [15,16], solar stills [17,18], cloud fertilizing [19,20], reclaimed water [21,22], and the production of freshwater from the atmosphere.

The world's atmosphere, with 14,000 km^3 of water, provides a vast and renewable source of water [23]. The extraction of water from the atmosphere is a new technique that relies on the compression and collection of atmospheric humidity [24]. The important point here is how to obtain water in a cost-effective manner. Condensate water produced by air conditioners can be a free source of water [25].

A few studies have been conducted to estimate the amount of water obtained from air conditioning systems and its quality [26–29]. According to a study conducted in Bandar Abbas in southern Iran, about 36 liters of water could be obtained from each air-conditioner. In the study, it was assumed that there were about 140,000–280,000 air-conditioners in Bandar Abbas, which could result in the production of a total of 50,400–100,800 m^3/water d [26]. Magrini et al. [28] designed a heating, ventilation, and air conditioning (HVAC) system in which air conditioning and water condensation were combined. It was reported that the designed system could provide about half of a hotel's demands.

Studies have shown that a significant amount of water can be produced by condensing atmospheric moisture, as previously noted. However, the quality of the condensate water from air conditioning systems is a major concern. The dissolving of ambient gases, as well as outdoor/indoor air particles entering the air conditioners, may cause the condensate water to be contaminated during its formation [30,31]. Atmospheric water quality is affected by pollutants present in the surrounding air [26]. As a result, high concentrations of heavy metals measured in the air of industrial and populated areas may create these elements in the water obtained from air conditioning systems. On the other hand, heavy metals may be present in the water as a result of contact with cooling coils and other components in air conditioning systems [32]. Previous studies have reported low concentrations of heavy metals in condensate water [33,34]. However, utilizing this water for irrigation might lead to greater concentrations of heavy metals in the soil and plants over time [32].

During the summer, air conditioners are extensively used to cool buildings. Therefore, atmospheric humidity condensation in air conditioners may provide a valuable source of water for various purposes. However, due to the existence of various industries in this city, the impact of air pollutants on the quality of the water is a significant issue. Therefore, this study aimed to investigate the quantity and quality of condensate water obtained from air conditioning systems.

2. Materials and methods

In this study, a total of 72 water samples were collected from air conditioners operating in commercial, official, and residential buildings in Kashan. Samples were taken in triplicate from six air conditioning brands, including General, O General, Gree, Samsung, LG, and Mitsubishi, with four different powers of 12,000; 18,000; 24,000 and 30,000 from mid-July to early September 2020.

Table 1
WHO and Iranian Standards for drinking water

Parameters	WHO Standards [3]	Iranian Standards [36]
EC (μmoh/cm)	–	–
Turbidity (NTU)	Maximum allowable: 5	Maximum allowable: 5
	Maximum desirable: 0.5	Maximum desirable: 1
TH (mg/L $CaCO_3$)	Maximum desirable: 100–200	Maximum desirable: 200
CO_2 (mg/L)	–	–
Nitrate (mg/L)	Maximum allowable: 50	Maximum allowable: 50
Alkalinity (mg/L)	–	–
pH	Maximum allowable: 8–8.5	Maximum allowable: 6.5–9
	Maximum desirable: 6–8.5	Maximum desirable: 6.5–8.5
TDS (mg/L)	Maximum allowable: 1,000	Maximum allowable: 1,500
	Maximum desirable: 600	Maximum desirable: 1,000
Chloride (mg/L)	Maximum desirable: 200	Maximum desirable: 250
Pb (mg/L)	Maximum allowable: 0.01	Maximum allowable: 0.01
Cd (mg/L)	Maximum allowable: 0.003	Maximum allowable: 0.003
Zn (mg/L)	Maximum desirable: 3	Maximum desirable: 3
As (mg/L)	Maximum allowable: 0.01	Maximum allowable: 0.01

WHO – World Health Organization;
NTU – Nephelometric turbidity unit.

All samples were collected in polyethylene bottles (1-L capacity) and immediately transferred to the laboratory for physical and chemical analysis. The levels of turbidity, electrical conductivity (EC), pH, total hardness (TH), zinc (Zn), lead (Pb), cadmium (Cd), arsenic (As), nitrate, alkalinity, carbon dioxide, total dissolved solids (TDS), and chloride were determined in the samples as described in Standard methods book for the examination of water and wastewater [35]. Heavy metals concentrations were determined using ICP Model 2400 DV Optima according to standard method number 3120B.

For statistical analysis, SPSS 26.0 software was used. The maximum, minimum, mean, and standard deviation of the analyzed parameters were determined using descriptive analysis. The levels of parameters in the samples were normally distributed (as determined by a Kolmogorov–Smirnov test). Therefore, the parametric ANOVA test was run to compare the parameter levels between the groups. Pearson's correlation determined the potential relationship between the analyzed parameters. A p-value of ≤0.05 was considered as significant.

3. Results

In this study, the quantitative and qualitative data of air conditioners' condensate water are presented in Tables 2 and 3. The standards for drinking water and effluent reuse in irrigation are also presented in Tables 1 and 2.

Table 2
FAO and Iranian Standards for effluent reuse in irrigation

Parameters	FAO Standards [37]	Iranian Standards [38]
Pb (mg/L)	5	1
Cd (mg/L)	0.01	0.05
Zn (mg/L)	2	2
As (mg/L)	0.1	0.1

Also, mean of humidity and temperature of air were 27.5% and 26.76°C, respectively.

The results of one-way analysis of variance showed no significant difference according to the brand and power of the air conditioner in the amount of physical and chemical parameters and the amount of condensate water recovered from the air conditioner. A significant difference between the concentrations of lead and arsenic was observed in different brands of air conditioners. However, no significant difference was confirmed for other heavy metals.

4. Discussion

Electrical conductivity (EC) in the recovered water from air conditioners ranged from 0.7 to 15.25 μmoh/cm and the mean was 5.7 μmoh/cm, which was lower than the amount reported in the study of Alipour et al. [26] in Bandar Abbas, Iran (42.55 μmoh/cm) [26], Noutcha et al. [29] in Nigeria (24.4 μmoh/cm) [29], Siam et al. [39] in Palestine (79.4 μmoh/cm) [39], and Scalize et al. [40] in Brazil (19.23 μmoh/cm).

The mean TDS levels of the water ranged from 8 to 42.5 mg/L which were less than the desirable value and the allowable standard number 1053 of Iran Industrial Standard Institute [36] as well as the WHO guideline [3]. The TDS level measured in our study was more than the TDS amounts determined in Nigeria (12.6 mg/L) [29] and Brazil (18.5 mg/L) [40] but lower than TDS amounts reported in Alipour et al. [26] study in Bandar Abbas, Iran (31.7 mg/L) [25,26] and Siam et al. [39] in Palestine (42.48 mg/L) [39]. It was documented that condensate water from near-sea locations (e.g., Bandar Abbas [26]) had a greater salinity.

The mean of alkalinity was 24 mg/L, which is regarded as low alkalinity. Water samples had a slightly acidic pH (~6) which was probably related to the presence of gases such as CO_2 in the air. The water pH from air conditioners in all brands and powers except Samsung brand and power 18,000 was lower than the allowable standard

Table 3
Mean and standard deviation of physical and chemical characteristics of water gained from air conditioners regard to the brand of system

Parameters \ Brands	LG	Samsung	O General	General	Mitsubishi	Gree	p-value
EC (μmoh/cm)	0.8 ± 0.3	3.01 ± 4.36	0.72 ± 0.54	2.09 ± 1.6	14.96 ± 15.7	12.8 ± 24.13	0.367
Turbidity (NTU)	0.96 ± 0.86	1.3 ± 0.7	0.96 ± 0.7	1.19 ± 0.4	0.37 ± 0.14	1.36 ± 0.86	0.455
TH (mg/L $CaCO_3$)	13.75 ± 3.86	16.50 ± 5.5	13.50 ± 6.19	11.25 ± 2.75	9 ± 2.58	18 ± 4.32	0.094
CO_2 (mg/L)	8.4 ± 1.2	8.58 ± 3.16	5.25 ± 0.72	8.03 ± 3.9	11.16 ± 12.01	6.6 ± 2.7	0.747
Nitrate (mg/L)	2.077 ± 0.85	1.67 ± 1.4	1.3 ± 0.1	2.3 ± 1.3	1.88 ± 1.8	1.26 ± 0.26	0.745
Alkalinity (mg/L)	27 ± 9.4	29.5 ± 5.1	20 ± 9.1	28.6 ± 15.3	19.5 ± 4.2	19.4 ± 9.5	0.417
pH	6.3 ± 0.16	6.5 ± 0.22	6.14 ± 0.28	6.4 ± 0.34	6.2 ± 0.13	6.2 ± 0.33	0.359
TDS (mg/L)	8 ± 5.4	40 ± 29.44	20 ± 27.08	20 ± 18.26	20 ± 14.14	42.5 ± 20.6	0.195
Chloride (mg/L)	23.76 ± 4.78	20.6 ± 6.58	18.76 ± 4.8	26.26 ± 7.5	19.38 ± 4.26	19.6 ± 4.6	0.377
Pb (mg/L)	0.04 ± 0.005	0.043 ± 0.003	0.04 ± 0.004	0.028 ± 0.006	0.028 ± 0.0045	0.034 ± 0.003	<0.001
Cd (mg/L)	0.0050 ± 0	0.0052 ± 0.0005	0.0053 ± 0.0005	0.0050 ± 0	0.0050 ± 0	0.0050 ± 0	0.56
Zn (mg/L)	0.265 ± 0.03	0.36 ± 0.1	0.3 ± 0.04	0.27 ± 0.06	0.4 ± 0.25	0.27 ± 0.037	0.47
As (mg/L)	0.04 ± 0.002	0.04 ± 0.006	0.04 ± 0.002	0.046 ± 0.006	0.045 ± 0.004	0.03 ± 0.004	<0.001

Table 4
Mean and standard deviation of physical and chemical characteristics of water gained from air conditioners regard to the power of system

Parameters \ Powers (W)	12,000	18,000	24,000	30,000	*p*-value
EC (μmoh/cm)	15.29 ± 19.97	5.24 ± 1.07	0.7 ± 0.26	1.69 ± 1.4	0.137
Turbidity (NTU)	1.05 ± 0.8	0.76 ± 0.44	1.095 ± 0.77	1.2 ± 0.9	0.77
TH (mg/L $CaCO_3$)	12.67 ± 4.7	13.83 ± 5	13.67 ± 5.4	14.50 ± 5.93	0.94
CO_2 (mg/L)	7.8 ± 3.6	6.5 ± 1.8	8.5 ± 6.8	7.8 ± 3.2	0.45
Nitrate (mg/L)	1.4 ± 0.5	1.6 ± 1.23	1.9 ± 1.4	2.04 ± 1.14	0.76
Alkalinity (mg/L)	21.3 ± 7.5	31.5 ± 10.7	23.9 ± 7.9	19.3 ± 9.09	0.12
pH	6.25 ± 0.3	6.5 ± 0.2	6 ± 0.16	6.2 ± 0.3	0.18
TDS (mg/L)	31.7 ± 19.4	22 ± 11.3	25 ± 39	21.7 ± 13.3	0.87
Chloride (mg/L)	18.06 ± 3.05	22.9 ± 7.15	19.6 ± 3.3	25 ± 6.32	0.13
Pb (mg/L)	0.03 ± 0.0056	0.03 ± 0.0074	0.036 ± 0.0078	0.03 ± 0.009	0.8
Cd (mg/L)	0.0050 ± 0	0.0050 ± 0	0.0052 ± 0.0004	0.0052 ± 0.0004	0.58
Zn (mg/L)	0.3 ± 0.04	0.4 ± 0.2	0.28 ± 0.05	0.3 ± 0.1	0.37
As (mg/L)	0.04 ± 0.004	0.04 ± 0.0037	0.04 ± 0.007	0.04 ± 0.006	0.3

number 1053 of Iran Industrial Standard Institute [36] and in all cases, it was less than the allowable amount in WHO instructions.

CO_2 concentration ranged from 5.26 to 11.6 mg/L with the mean of 8 mg/L. Carbonate part of the alkalinity has a significant relationship with the hardness of water. Naturally, the alkalinity and the hardness of water are low. The alkalinity amount in this study was more than the amount reported in Nigeria (15.4 mg/L) [29] and lower than that in Bandar Abbas (36–35 mg/L) [25,26].

The level of hardness was in the standard range and the mean was 13.67 mg/L $CaCO_3$. The hardness of water from air conditioners in Kashan was lower than the allowable standard level of Iran Industrial Standard Institute (No. 1053) [36] and lower than the allowable amount in the WHO guideline [3] (Table 1). This was a soft water, which may cause corrosion of metal parts of the air conditioner, so the pH adjustment for the industrial use of such water is necessary [41,42]. Based on earlier research, the hardness was higher than the amount reported in Nigeria (12.33 mg/L $CaCO_3$) [29], and in Palestine (3.6 mg/L $CaCO_3$) [39] and lower than that in Bandar Abbas (19.37 mg/L $CaCO_3$) [25,26].

The mean nitrate concentration of the water from the air conditioners was 1.26–2.327 mg/L with the mean of 1.75 mg/L, which was lower than both the allowable standard of Iran Industrial Standard Institute (No. 1053) [36] and the levels suggested in the WHO guideline [3]. The concentration of nitrate in this study was lower than the nitrate content of the condensate water in Nigeria (15.27 mg/L) [29]. The turbidity of condensate water ranged from 0.37 to 1.36 NTU and its mean was 1.03 NTU. According to the standard, the amount of water turbidity of water recovered from the air conditioners in Kashan was lower than the allowable amount. The water turbidity could be due to the diffusion of particles from vehicles or dust from the air. The turbidity amount in this study was lower than similar studies in Nigeria (5 NTU) [29] and Bandar Abbas (2.43 NTU) [25,26], but more than that in Brazil (less than 0.4 NTU) [40].

Chloride concentration was 18.6- 26.26 mg/L with a mean of 21.4 mg/L which was lower than Iranian Standard and the accepted value of WHO guideline. In a study conducted in Nigeria, the chloride amount was 123.67 mg/L in the first study and 5.6 mg/L in the second study.

The mean concentrations of heavy metals for each brand and the input power of air-conditioners are presented in Tables 2 and 3. The mean concentrations of lead, cadmium, zinc, and arsenic were 0.03, 0.00051, 0.31, and 0.04 mg/L, respectively. Concentrations of lead, cadmium, and arsenic were higher than the WHO and Iran allowable limits for freshwater consumption, so it is not recommended for drinking. However, it can be used for irrigation of ornamental flowers, green spaces at home, engine cooling systems, and also in industry for washing devices. The solubility of air pollutants in water or the reactivity of the water with metal components of the instruments might cause the presence of heavy metal in the condensate water. The slightly acidic nature of condensate water causes it to react with metal surfaces especially iron and steel in air conditioners. This can create metal ions and accumulation of metals in water if metal tubes are used for irrigation hence maintaining these metals in the soil for a long time [32]. However, Table 2 reveals that the concentration of lead, cadmium, zinc, and arsenic in the water harvesting from air conditioners are in accordance with the FAO [37] and Iran Irrigation Standards [38].

In our study, a significant difference in lead and arsenic concentrations in different brands of air-conditioners was observed ($P < 0.001$), which was probably related to the reaction of water with metal components in different instruments. The results of Siriwardhena and Ranathunga [34] study showed a minor hazard posed by the contamination of the water by lead from solder joints in the coils of air conditioners. In a study conducted in Nigeria [29], the lead value was more than the desirable amount and ranged 0.03–0.06, but the study in Palestine [39] showed no lead in the samples. Given the presence of many different

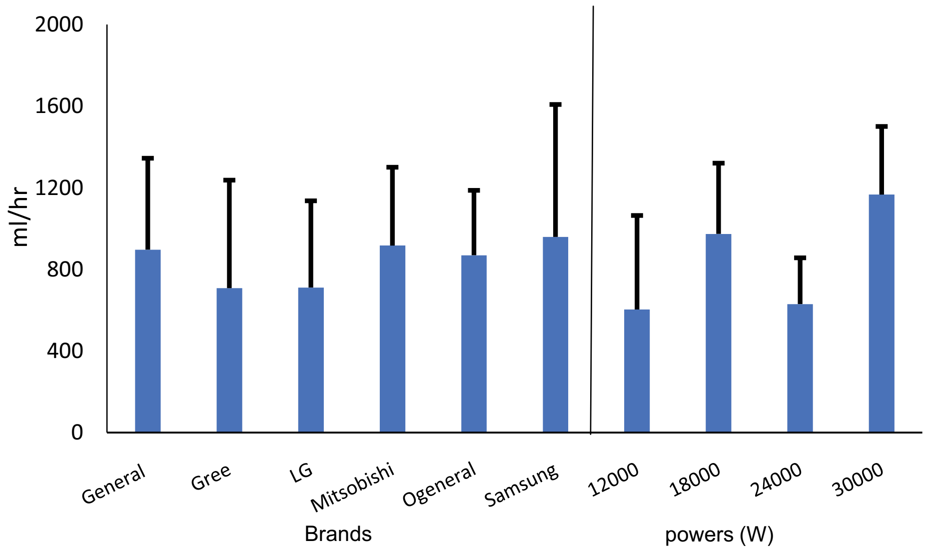

Fig. 1. Mean and standard deviation of the condensate water quantity from the air conditioners according to the power and brand of air conditioner.

industries and motor vehicles in Kashan, the concentration of heavy metals in the air is possibly high. In studies conducted in other cities in Iran, high levels of heavy metals in the ambient air were reported. The studies indicated that the concentrations of arsenic, cadmium, and nickel in Isfahan [43], cadmium and nickel in Tehran [44], and lead, copper, nickel, and chromium in some parts of Arak [45] were higher than the acceptable values.

Also, the mean values of relative humidity (RH%) and temperature of the air were 27.5% and 26.76°C, respectively.

As is shown in Fig. 1, the amount of condensate water taken from different types of air-conditioners ranged from 0.6 to 1.2 L/h (mean: 0.83 L/h). Statistical analysis showed no significant difference between the quantity of water recovered from different brands and input powers of the selected air-conditioners. It was reported that the relative humidity plays a major role in the water recovery from air conditioners. Kashan is located in an arid area with low relative humidity. As expected, the quantity of water from air-conditioners in our study was lower than that in studies conducted in humid climates. In our study, the volume of extractable condensate water from air-conditioners was estimated at about 1 L/h which means the production of about 8 L/d of water, considering 8 h of operation in a day. In a study conducted in Brazil [40], the mean volume of water obtained from different powers, including 9,000; 12,000 and 24,000 W, was reported at about 4.25 L/h. In a study performed in Bandar Abbas [25,26], Iran, with a hot and humid climate, the mean quantity of the water recovered from split air conditioners and window air conditioners was 36 L/d for each instrument. Although our study was conducted in a dry area with low humidity in the ambient air, human activities such as bathing, showering, cooking, clothes washing, and floor washing create humidity indoors. Considering the severe water crisis in Kashan, condensation of the indoor air moisture in air conditioning systems can provide a valuable water source for domestic use.

5. Conclusion

Lack of water resources in most countries, especially in Iran, has become one of the major problems. To overcome this challenge, it is necessary to develop the new water resources. Therefore, the present study aims to investigate the use of a potential new sources of water, namely water harvesting from air conditioners. These systems produce a considerable amount of water in different climatic conditions depending on the air humidity, which is wasted as a by-product, while it can be managed effectively for non-drinking purpose. The results of this study indicate that the amount of water harvesting from home or commercial air conditioning system was considerable and its average value was about 0.83 L/h depending on the weather conditions in Kashan city. It was also found that the relationship between water harvesting and brand and its power of system was not statistically significant. In addition, based on chemical analysis, the concentration of some heavy metals in the harvested water was high due to air pollution in the region. Therefore, it cannot be used for drinking purposes, but it can be used for irrigation of ornamental flowers, toilet flash tanks, car windshield wipers, and engine cooling systems.

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Competing interest

The authors declare that there is no conflict of interest.

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Limitation

A limitation of this study was lack of access to all air conditioners in houses, offices, and commercial places. Also, there is a lack of a structure for collecting and reusing the condensate water, lack of public awareness and knowledge, as well as the possibility of microbial risk in high-risk locations.

References

[1] M. Shatat, S.B. Riffat, Water desalination technologies utilizing conventional and renewable energy sources, Int. J. Low-Carbon Technol., 9 (2014) 1–19.

[2] M.A. Abdelkareem, M.E.H. Assad, E.T. Sayed, B. Soudan, Recent progress in the use of renewable energy sources to power water desalination plants, Desalination, 435 (2018) 97–113.

[3] [3] WHO, Guidelines for Drinking-Water Quality, 4th ed., Incorporating First and Second Addenda, 2017. Available at: https://www.who.int/publications/i/item/9789240045064 (Accessed on 12 June 2022).

[4] J. Gasana, J. Morin, A. Ndikuyeze, P. Kamoso, Impact of water supply and sanitation on diarrheal morbidity among young children in the socioeconomic and cultural context of Rwanda (Africa), Environ. Res., 90 (2002) 76–88.

[5] J.M. Balbus, M.E. Lang, Is the water safe for my baby?, Pediatr. Clin. North Am., 48 (2001) 1129–1152.

[6] I.A. Al-Khatib, H.A. Arafat, Chemical and microbiological quality of desalinated water, groundwater and rain-fed cisterns in the Gaza strip, Palestine, Desalination, 249 (2009) 1165–1170.

[7] E.S. Fard, S. Dobaradaran, R. Hayati, Chemical, microbial and physical evaluation of commercial bottled drinking water available in Bushehr city, Iran, Fresenius Environ. Bull., 24 (2015) 3836–3841.

[8] V.N. Karbasdehi, S. Dobaradaran, F. Soleimani, H. Arfaeinia, M.J. Mohammadi, M. Keshtkar, R. Mirahmadi, The role of decentralized municipal desalination plants in removal of physical, chemical and microbial parameters from drinking water: a case study in Bushehr, Iran, J. Water Sanit. Hyg. Dev., 8 (2018) 325–339.

[9] A. Raeisi, F. Soleimani, S. Dobaradaran, M. Keshtkar, N. Karbasdehi, Microbial, chemical and physical properties of drinking water in Bushehr distribution network system, Desal. Water Treat., 65 (2017) 208–214.

[10] R. Emami, M. Hesami Arani, S.K. Ghadiri, E. Harasi, A. Ahmadfazeli, M. Tazik, Study of the reasons for tendency to use desalination systems in the Households of Bandar Lengeh, Hormozgan, Iran, J. Health Res. Community, 3 (2017) 29–37.

[11] E.H.B. de Gois, C.A.S. Rios, R.N. Costanzi, Evaluation of water conservation and reuse: a case study of a shopping mall in southern Brazil, J. Cleaner Prod., 96 (2015) 263–271.

[12] A. Panagopoulos, Techno-economic evaluation of a solar multi-effect distillation/thermal vapor compression hybrid system for brine treatment and salt recovery, Chem. Eng. Process. Process Intensif., 152 (2020) 107934, doi: 10.1016/j.cep.2020.107934.

[13] 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.

[14] X. Chen, H. Ozaki, R.R. Giri, S. Taniguchi, R. Takanami, Low-pressure reverse osmosis membrane separation of non-fluorinated and perfluorinated organic compounds in water, Desal. Water Treat., 52 (2014) 5796–5805.

[15] K.C. Ng, K. Thu, S.J. Oh, L. Ang, M.W. Shahzad, I.A. Bin, Recent developments in thermally-driven seawater desalination: energy efficiency improvement by hybridization of the MED and AD cycles, Desalination, 356 (2015) 255–270.

[16] J. Kavitha, M. Rajalakshmi, A.R. Phani, M. Padaki, Pretreatment processes for seawater reverse osmosis desalination systems—a review, J. Water Process Eng., 32 (2019) 100926, doi: 10.1016/j.jwpe.2019.100926.

[17] S. Shoeibi, N. Rahbar, A.A. Esfahlani, H. Kargarsharifabad, A comprehensive review of Enviro-Exergo-economic analysis of solar stills, Renewable Sustainable Energy Rev., 149 (2021) 111404, doi: 10.1016/j.rser.2021.111404.

[18] S. Yadav, K. Sudhakar, Different domestic designs of solar stills: a review, Renewable Sustainable Energy Rev., 47 (2015) 718–731.

[19] R.M. Rauber, B. Geerts, L. Xue, J. French, K. Friedrich, R.M. Rasmussen, A.S. Tessendorf, D.R. Blestrud, M.L. Kunkel, S. Parkinson, Wintertime orographic cloud seeding—a review, J. Appl. Meteorol. Climatol., 58 (2019) 2117–2140.

[20] K. Friedrich, K. Ikeda, S.A. Tessendorf, J.R. French, R.M. Rauber, B. Geerts, L. Xue, R.M. Rasmussen, D.R. Blestrud, M.L. Kunkel, N. Dawson, S. Parkinson, Quantifying snowfall from orographic cloud seeding, Proc. Natl. Acad. Sci., 117 (2020) 5190–5195.

[21] J.C. Intriago, F. López-Gálvez, A. Allende, G.A. Vivaldi, S. Camposeo, E.N. Nicolás, J.J. Alarcón, F.P. Salcedo, Agricultural reuse of municipal wastewater through an integral water reclamation management, J. Environ. Manage., 213 (2018) 135–141.

[22] S. Bunani, E. Yörükoğlu, G. Sert, Ü. Yüksel, M. Yüksel, N. Kabay, Application of nanofiltration for reuse of municipal wastewater and quality analysis of product water, Desalination, 315 (2013) 33–36.

[23] M. Kumar, A. Yadav, Solar-driven technology for freshwater production from atmospheric air by using the composite desiccant material "$CaCl_2$/floral foam", Environ. Dev. Sustainability,18 (2016) 1151–1165.

[24] M. Qadir, G.C. Jiménez, R.L. Farnum, L.L. Dodson, V. Smakhtin, Fog water collection: challenges beyond technology, Water, 10 (2018) 372, doi: 10.3390/w10040372.

[25] A. Mahvi, V. Alipour, L. Rezaei, A. Nohegar, M. Hosainzadeh, Qualitative and quantitative study of water obtained from condensate atmosphere humidity in Bandar Abbas air conditioners, Hormozgan Med. J., 18 (2014) 67–74.

[26] V. Alipour, A.H. Mahvi, L. Rezaei, Quantitative and qualitative characteristics of condensate water of home air conditioning system in Iran, Desal. Water Treat., 53 (2015) 1834–1839.

[27] A. Magrini, L. Cattani, M. Cartesegna, L. Magnani, Integrated systems for air conditioning and production of drinking water–preliminary considerations, Energy Procedia, 75 (2015) 1659–1665.

[28] A. Magrini, L. Cattani, M. Cartesegna, L. Magnani, Water production from air conditioning systems: some evaluations about a sustainable use of resources, Sustainability, 9 (2017) 1309, doi: 10.3390/su9081309.

[29] M. Noutcha, O. Damiete, M. Johnny, O. Ngozi, C. Ezera, S. Okiwelu, Quantity and quality of water condensate from air conditioners and its potential uses at the University of Port Harcourt Nigeria, Adv. Appl. Sci. Res., 7 (2016) 45–48.

[30] A.S. Sánchez, E. Cohim, R.A. Kalid, A review on physicochemical and microbiological contamination of roof-harvested rainwater in urban areas, Sustainability Water Qual. Ecol., 6 (2015) 119–137.

[31] O. Inbar, A. Chudnovsky, K. Ohneiser, A. Ansmann, S. Ratner, R. Sirota, Y. Aviv, D. Avisar, Air-water interactions: the signature of meteorological and air-quality parameters on the chemical characteristics of water produced from the atmosphere, Sci. Total Environ., 790 (2021) 147940, doi: 10.1016/j.scitotenv.2021.147940.

[32] S. Algarni, C.A. Saleel, M.A. Mujeebu, Air-conditioning condensate recovery and applications—current developments and challenges ahead, Sustainable Cities Soc., 37 (2018) 263–274.

[33] K. Guz, Condensate water recovery, ASHRAE J., 47 (2005) 54.

[34] K. Siriwardhena, S. Ranathunga, Air-Conditioners Condensate Recovery System for Buildings, International Conference on Sustainable Built Environment–ICSBE, University of Moratuwa, Sri Lanka, 2012.

[35] APHA/AWWA/WEF, Standard Methods for the Examination of Water and Wastewater, 23rd ed., American Public Health Association, American Water Works Association, Water Environment Federation, Denver, 2017.

[36] J. Shayegan, P. Raufian, Iran Standard Number 1053, Institute of Standards and Industrial Research of Iran, 2 (1351) 1–100.
[37] R.S. Ayers, D. Wescot, Water Quality for Agriculture, Food and Agriculture Organization of the United Nations, Rom, 1994.
[38] Research Department of Environmental Protection Organization of Iran, Effluent–Discharge Standards, Burro of Environmental Education Publications, Tehran, 1994.
[39] L. Siam, I.A. Al-Khatib, F. Anayah, S. Jodeh, G. Hanbali, B. Khalaf, A. Deghles, Developing a strategy to recover condensate water from air conditioners in Palestine, Water, 11 (2019) 1696, doi: 10.3390/w11081696.
[40] P.S. Scalize, S.S. Soares, A.C.F. Alves, T.A. Marques, G.G.M. Mesquita, N. Ballaminut, A.C.J Albuquerque, Use of condensed water from air conditioning systems, Open Eng., 8 (2018) 284–292.
[41] A.H. Mahvi, V. Alipour, L. Rezaei, Atmospheric moisture condensation to water recovery by home air conditioners, Am. J. Appl. Sci., 10 (2013) 917–923.
[42] E. Gharehchahi, A.H. Mahvi, S.M.T. Shahri, R. Davani, Possibility of application of kenaf fibers (*Hibiscus cannabinus* L.) in water hardness reduction, Desal. Water Treat., 52 (2014) 6257–6262.
[43] M. Soleimani, N. Amini, B. Sadeghian, D. Wang, L. Fang, Heavy metals and their source identification in particulate matter (PM2. 5) in Isfahan City, Iran, J. Environ. Sci., 72 (2018) 166–175.
[44] M. Kermani, H. Arfaeinia, R. Nabizadeh, M. Alimohammadi, A.A. Aalamolhoda, Levels of PM2.5 - associated heavy metals in the ambient air of Sina hospital district, Tehran, Iran, J. Air Pollut. Health, 1 (2016) 1–6.
[45] F. Ghadimi, M. Ghomi, M. Ranjbar, A. Hajati, Statistical analysis of heavy metal contamination in urban dusts of Arak, Iran, Iran. J. Energy Environ., 4 (2013) 406–418.