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The influence of household filter types on quality of drinking water

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ABSTRACT

Point-of-use (POU) water filters nowadays are widely used worldwide to get highly purified potable water. In this study, people opinions about household water filters were obtained via well-constructed questionnaire distributed to 1200 participants in the state of Kuwait. Analyses revealed that respondents installed multiple household filtration systems due to the doubts that municipal water could include physical (40 %), chemical (36 %), and biological contaminants (31 %) that induces infectious and non-infectious diseases. Subsequently, total of 56 waters samples without and after using POU filters were collected from 28 homes in Kuwait distributed over all residential areas of Kuwait. The POU water filters were not found efficient to remove physical, chemical, and microbiological parameters and conversely water quality deteriorated in most houses after the POU filters. This is possibly due to lack of tanks and filter maintenance and therefore POU filters became reservoirs of various types of chemical, physical, and microbial impurities. Based on results of questionnaires, published studies, and market study, a testing station was developed and eight different configurations of household water filters were investigated for 10 continues months. Results demonstrated that singular filters can efficiently remove water impurities if these household filters undergo to periodic cleaning activities. Removal efficiency of filters, with a proper regeneration, varied from 75 % (carbon wrapped filter) to 91 % (ceramic filter) for turbidity, from 58 % (polyspun filter) to 83 % (ceramic filter) for total coliforms, and 100 % for TSS with all filters over the tested period.

1. Introduction

The need of sustainable clean water supply, free of waterborne microbes and undesirable chemicals, has become the top priority of most people, especially in developing countries, as there is limited or no fresh water resources. According to the world health organization (World Health Organization (WHO, 2019), there are about 2 billion people, mostly live in developing countries, use contaminated water, originated from unprocessed surface resources like lakes, rivers, and ponds, for drinking purposes. In addition to that, homes tanks could be a reservoir of unwanted chemicals and various type of microorganisms that formed during transportation of municipal water to residential houses or formed in tanks if not properly closed, maintained, or regenerated (Jensen et al., 2004; Sobsey et al., 2008).

Drinking contaminated water can cause numerous detrimental health symptoms and dieses including polio, vomiting, dysentery, gastroenteritis, cholera, typhoid, and diarrhea (Plutzer and Karanis, 2016). According to WHO statistics (World Health Organization (WHO, 2019), lack of sanitation, polluted surface and ground water resources, and bad hygiene measures has led to 4.0 % of total fatalities and 6% of total debility in the world. Furthermore, it was reported that about 500 thousand incidents of diarrhoeal deaths each year caused by ingestion of polluted water (World Health Organization (WHO, 2019).

The increased doubts about water sanitization had led consumers to believe that there is an urgent need for proper water filtration systems to enhance the quality and safety of potable water. Thus, the point-of-use (POU) and point-of-entry (POE) filters are commonly used and the water filters market size increased. POU is a filtration system placed at a single tap or few taps to treat water for drinking and cooking purposes while POE are devices usually installed at main water line to purify all water entering a single house, commercial and government building or facility (United States Environmental Protection Agency (US EPA), 2006). These household filters available in the market differ from each other by filtration and regeneration technique, the targeted size and type of contaminants, and the desired removal efficiency of pollutants (Slotnick et al., 2006; Cotruvo et al., 2014).

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Despite the fact that household filters market size is continuously increased, limited studies have been conducted for determining the best commercial home's household filters. Previous researcher evaluated the POU and POE filters including pot and candle ceramic filters (Mwabi et al., 2011; Mellor et al., 2014; Berg, 2015), sand and biosand filters (Murphy et al., 2010; Liu et al., 2019; Goel and Chauhan, 2019), membrane filters (Han et al., 2013; Pérez-Vidal et al., 2016) and activated carbon based filters (Bhatnagar et al., 2013; Smith and Rodrigues, 2015). Overall, these filtration systems have been proven to remove suspended solids and microbiological contaminants. It is imperative to highlight that the formation of biofilms in water distribution network may pose detrimental risks on human health as it will act as a reservoir for hazardous microorganisms (Bressler et al., 2009; Feazel et al., 2009). Additionally, the lack of proper regeneration and maintenance of POU and POE filters can deteriorate the quality of water as the water would be contaminated with chemical and microbiological impurities building-up inside the filters (Massieux et al., 2004).

Although there are number of studies investigated the performance of different filtration systems, most of these investigations have been performed in short time duration and with limited parameters (Chaidez and Gerba, 2004; Ahmad and Davra, 2011; Vidal et al., 2018). This study aimed to measure people awareness about the use of household filtration systems through developed questionnaire distributed to 1200 participants residing in all residential cities in the state of Kuwait. Additionally, the physical, chemical, and microbiological parameters of water sample before and after filtration systems of twenty-eight residential houses in Kuwait representing all six governorates of Kuwait were quantified. Furthermore, a testing station was built at Kuwait university to evaluate the removal efficiency of eight different water filtration systems configurations for 10 continues months. Up to the knowledge of the authors, no such study has been ever done in the state of Kuwait to systematically investigate the physical, chemical, and biological parameters of household water prior and after different types of household filters and thus this study was performed.

2. Material and methods

2.1. Questionnaire about people perception on household water filters

A questionnaire was developed to measure the awareness level in the society about the use of water filters and their confidence in water pumped to their houses via governmental water network (Table S2). The questionnaire was tailored to identify demographic information, types of water sources used in houses, frequency of household filter use, and knowledge and perceptions of drinking water-related water treatment and diseases. Additionally, information regarding the frequency of tank and filters maintenance were also collected. The demographic profile of respondents is shown in Fig. 1. Respondents were 1200 adults distributed in the six governorates of Kuwait; 54 % of respondents were males and 46 % were females. Respondents were in different age categories; 3% under the age of 18, 34 % were between 18 and 25, 43 % were between the ages of 26 and 40, and 20 % were 40 and over. Regarding level of educations, 7% of respondents were below the high school level, 13 % were achieved high school education, 67 % completed a bachelor's degree, and 13 % have higher education degree. Participants were informed about purpose and aims of this study and agreed to support this study.

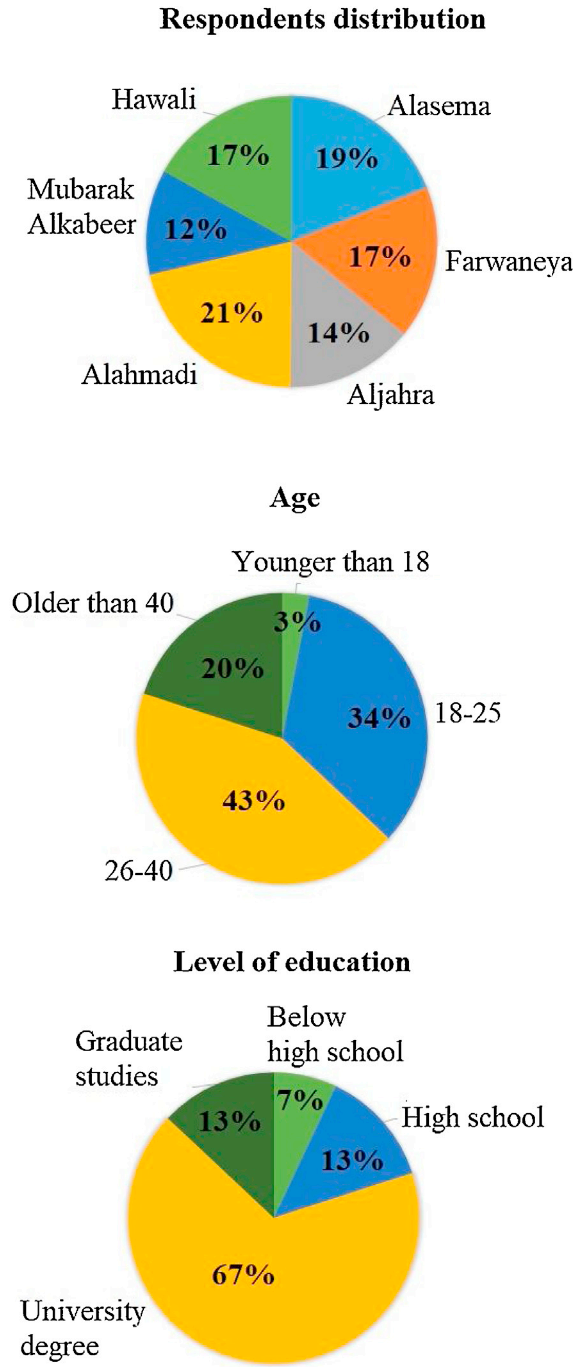

Fig. 1. Demographic profile of respondents in this study.

2.2. Water samples collection from residential houses

Water samples with and without using household water filtration systems were collected from twenty-eight houses (total of 56 samples) distributed in all six governorates (Alasima, Farwaniya, Hawali, Mubark Alkabeer, Aljahra and Alahmadi) in the State of Kuwait. Samples were collected randomly in each governorate between the year of 2016 and 2017. Water specimens were collected in a sterilized 2 L plastic bottle. After the collection, samples were sealed to avoid cross contaminations and placed in ice box to maintain a temperature of about 4 °C. Collected samples were immediately submitted to Kuwait university water testing laboratories for chemical and physical parameters and biological labs for microbiological quantifications.

2.3. Installation of testing station for different configurations of household water filters

To gain better understanding about the removal efficiency of commonly used household water filters, a testing station was built at Kuwait University and equipped with air-conditioning to mimic the actual home environment. The selection of household water filters was based on results of questionnaires, published studies, and market study. Eight different configurations of household water filters were investigated for 10 continues months, from April 2017 to January 2018. The eight household water filters configurations tested (Figure S1) included single filtration systems (Polyspun filter (PF), sand filter (SF), ceramic filter (CF), reverse osmosis filter (ROF), carbon wrapped filter(CNRF)), dual filtration systems (Polyspun filter (PF) + carbon block filter(CNBF), ceramic filter (CF) + carbon block filter(CNBF)) and triple filtration systems (Polyspun filter (PF) + carbon block filter(CNBF) + carbon wrapped filter(CNRF)). The specifications of 8 POU used in this study are summarized in Table S1. Samples were collected on weekly basis without and after using each household water filters configurations. Water discharge system was installed and connected to nearest green area for irrigation purposes. Sampling and preservation procedures were similar to those described above (sample collection section). When the performance of filters declines at 150 days, the main waterline is shut down and water is drained from filters. Subsequently, filters were removed from housing systems and cleaned using a hose and brush to scrub down the filter. Prior putting the filter back, the water is turned on for few seconds to push out suspended particles that might be in the pipe. The filter was then placed back into its housing.

2.4. Sample analysis

The physical, chemical, and biological parameters of water samples without and after using filters were quantified. The selected parameters were as follows: pH, electrical conductivity (EC), total suspended solids (TSS), total dissolved solids (TDS), turbidity, salinity, metal analysis, nitrate/nitrite, nitrite, total phosphorus (TP), total organic carbon (TOC), and a total microbial (aerobic) number. Metal analysis was performed using inductively coupled plasma, optical emission spectrometer (PerkinElmer Optima 7300 ICP-OES). Nitrate/nitrite and total phosphorus concentrations were determined by Lachat Flow Injection Analyzer, Lachet Instrument Quik Chem 8500 series. The nitrite (which is present plus reduced nitrate) is measured by diazotization with sulfanilamide and bonding with N-(1-naphthyl)–ethylenediamine dihydrochloride (NED) to form a pink dye that is measured colorimetrically at 540 nm. Total organic carbon (TOC) content was measured by TOC analyzer (Shimadzu-VCPH, SSM-5000A. The CO_2 is detected and quantitated by the non-dispersive infra-red detector (NDIR). Total dissolved solids (TDS) and total suspended solid (TSS) were quantified using glass fiber filter using a vacuum pump. Water sample turbidity was measured via Turbidity Meter (Nephelometric) WTW Turb 550 IR. Conductivity of water samples was measured using a commercial conductivity cell with platinum electrodes. Measurements of water samples pH were determined using Fisher Scientific Apparatus, Accumet AR50. The total microbial (aerobic) number was analyzed using membrane filtration method (MF-8074). To maintain quality control and quality assurance, laboratory and field blanks and standard spiked recoveries were analyzed. Recoveries of water parameters ranged from 85−115 %.

2.5. Statistical analysis

The profile of water samples parameters without and after using filtration systems were illustrated by boxplot analysis. The differences among the means of water samples parameters without and after using filtration systems were quantified using one-way analysis of variance (ANOVA) followed by post hoc analysis with a significance level (α) of 0.05. All statistical analyses were performed using open source R project software.

3. Results and discussion

3.1. Opinions on the use of household filters in improving water quality

Tap water is the main sources of potable water sources in Kuwait, which is delivered from desalination plants by pipe systems to residential household. Like other parts of the worlds, some people tend to use bottled water for esthetic factors for drinking, but not for cooking and other household activities in Kuwait. According to survey of 1200 respondents (Fig. 2), majority of houses owners (79–84 %) use filtered tap water, 1–16 % use bottled water, and 5−15% do not use filter for drinking and cooking activities. Results showed that 54 % of respondents lacks the confidence in water due to source contamination (sea water) (33 %), water storage tank and its network (58 %), and majority (∼72 %) attributed to less hygiene practices of governmental water supply network throughout collection, storage and transfer to houses. Thus, about 94.7 % of respondents in Kuwait use household filters at their houses to receive highly purified water (51 %). Respondents used both single filters and integrated filtration systems of polyspun filter, sand filter, ceramic filter, reverse osmosis filter, carbon block filter, and carbon wrapped filter. Results showed that house owners use water filters to eliminate or reduce physical (40 %), chemical (36 %), and biological contaminants (31 %). Water can include grime, chemicals, crystals and other contaminates that induce changes in taste and smell (Baergen and Donaldson, 2019). Bacteria and microscopic organisms may cause infectious diseases and non-infectious chronic diseases like coronary heart disease (Cassell, 1998; Plutzer and Karanis, 2016). Household filters may help cleanse water, removing these contaminates and making it safe to drink, while usually enhancing its taste (Barth et al., 2017). The survey also revealed that majority of respondents (∼77 %) install their filters in kitchen and 38 % of them maintain their household filters when the taste of water changes, while about 15 %, 21 %, 11 % and 7% % maintain their household filters every one year, 6 months, 3 months and one month, respectively. As a precautionary measure, 86 % of respondents confirmed that they cover their water tank to protect them from contaminations, while 14 % leave their tanks without covering. Additionally, the survey showed that 14 % of respondents maintain their water tank every year, 13 % every three years, about 38 % of respondents have poor knowledge about the maintenance, and 31 % of respondents never performed tank maintenance.

3.2. Analysis of the physical, chemical and microbiological parameters of household water samples without and after using filtration systems

Fifty-six water samples were collected from 28 houses distributed in all six governorates in the state of Kuwait. Two samples were collected from each house; one without using filter and another after using the filter. The pattern and distribution of chemical, physical and microbiological parameters of water samples without and after using household filters are illustrated using boxplots and results are shown in Fig. 3. In terms of regulatory abidance,

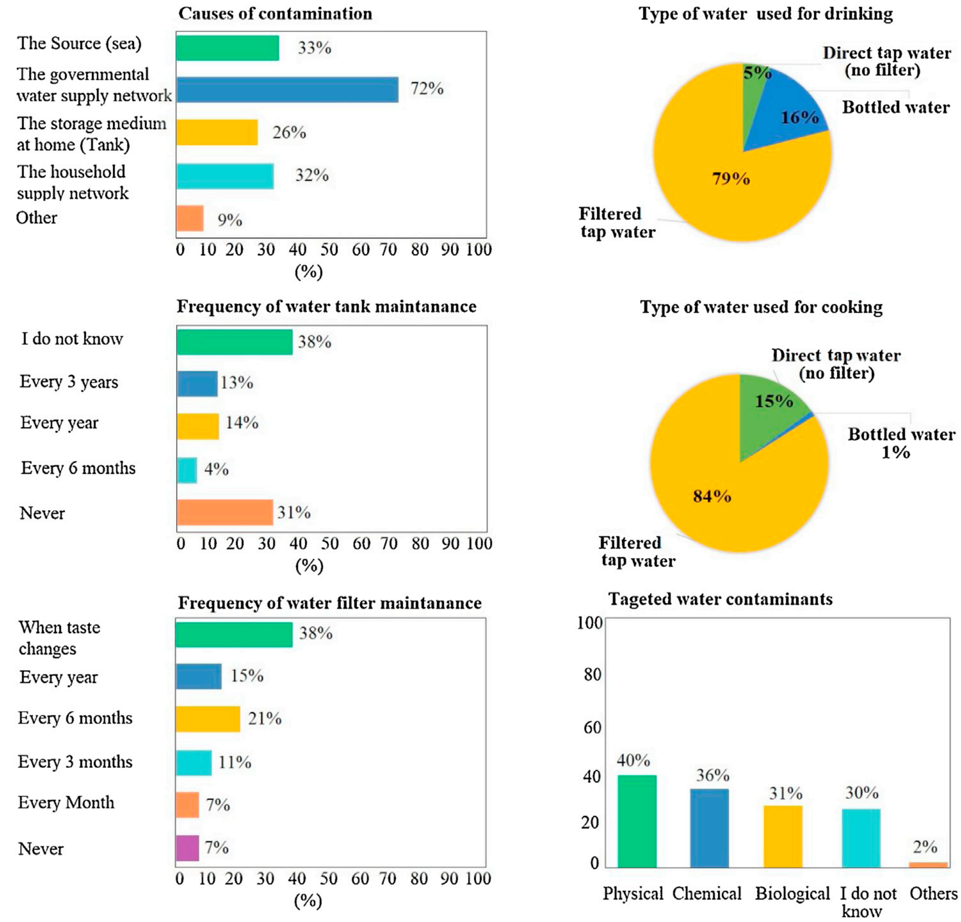

Fig. 2. Respondents answers related to water contamination sources, and information related to household water filter.

all physical, chemical, and microbiological parameters were within the permissible levels of USA EPA, WHO, and Kuwait (Tables S3 and S4) water quality regulations for drinking water. Based on ANOVA analyses, no significant statistical differences (p-value>0.05) were observed in TDS, nitrate/nitrite, metals contents, pH, and conductivity without and after using filter. The average values of TDS ranged from 48 to 110 mg/l, nitrate/nitrite from 0.04 to 0.17, and sodium contents from 5.2 to 11 mg/l in all governorates (Fig. 3). The conductivity of water samples with and without water filters varied between 230 and 255 μS/cm and pH of all samples were within the WHO acceptable limit (6.5–8.5), figures are not shown for sake of brevity. Conversely, significant statistical differences (p-value<0.05) were observed in turbidity, total coliforms, and TSS values without and after using water filters and among governorates. Surprisingly, turbidity, total coliforms, and TSS values before the filters were lower than those after water filters. These discrepancies could be possibly related mainly to two reasons; water tank maintenance (without using filters) and water filter maintenance. According to the survey, 30 % of house owners never cleaned their tanks and 38 % fail to know the last time cleaned their tanks while 38 % do not clean their filters unless they feel change in taste or colors. This indeed demonstrates the low efficiency of filtration systems, as filters could be considered as a reservoirs of various types of chemical, physical, and microbial impurities (Nriagu et al., 2018). It should be highlighted that these household filters are efficient for microorganism removal, but they are highly impacted by the regeneration and cleaning events (Gupta et al., 2018; Pérez-Vidal et al., 2019). Analysis of Pearson correlation coefficient (R) between turbidity and total coliforms obtained from all waters irrespective of filters types varied from 0.55 to 0.62, with an average of 0.6, and with no statistical differences among filters ($p > 0.05$). Such observation indeed shows that increasing the water turbidity induce the growth of microorganism and therefore filters would act as a sink for microbial and other water impurities. As per governorates, lowest level of turbidity, total coliforms, and TSS were observed in Hawali and Alahmadi governorates and highest were found in Aljahra governorate. Residential houses in Hawali and Alahmadi governorates were mostly utilizing single polyspun filter (PF) while other governorates were commonly using dual and triple filtration systems configurations. This indicates that single filtration system could be less impacted from the poor and lack of tank and filter maintenance compared with dual and triple filtrations systems.

3.3. Performance of different filtration systems configurations on water quality

To increase people awareness about filtration systems, the physical, chemical, and microbiological parameters of water samples before and after of different filtration systems configurations were monitored for 10 continuous months using a designed testing station. The removal efficiency (%) results of different filtration systems configurations are shown in Fig. 4. Statistical differences among the means of physical, chemical, and biological parameters of water samples without and after using filtration systems were evaluated via one-way analysis of variance (ANOVA) followed by post hoc analysis against alpha of 0.05. Table 1 illustrates the detailed results of ANOVA tests. The level of salinity, total phosphorus and the total organic carbon in water samples with and without filters were below the lower limit of detection (LOD) through-

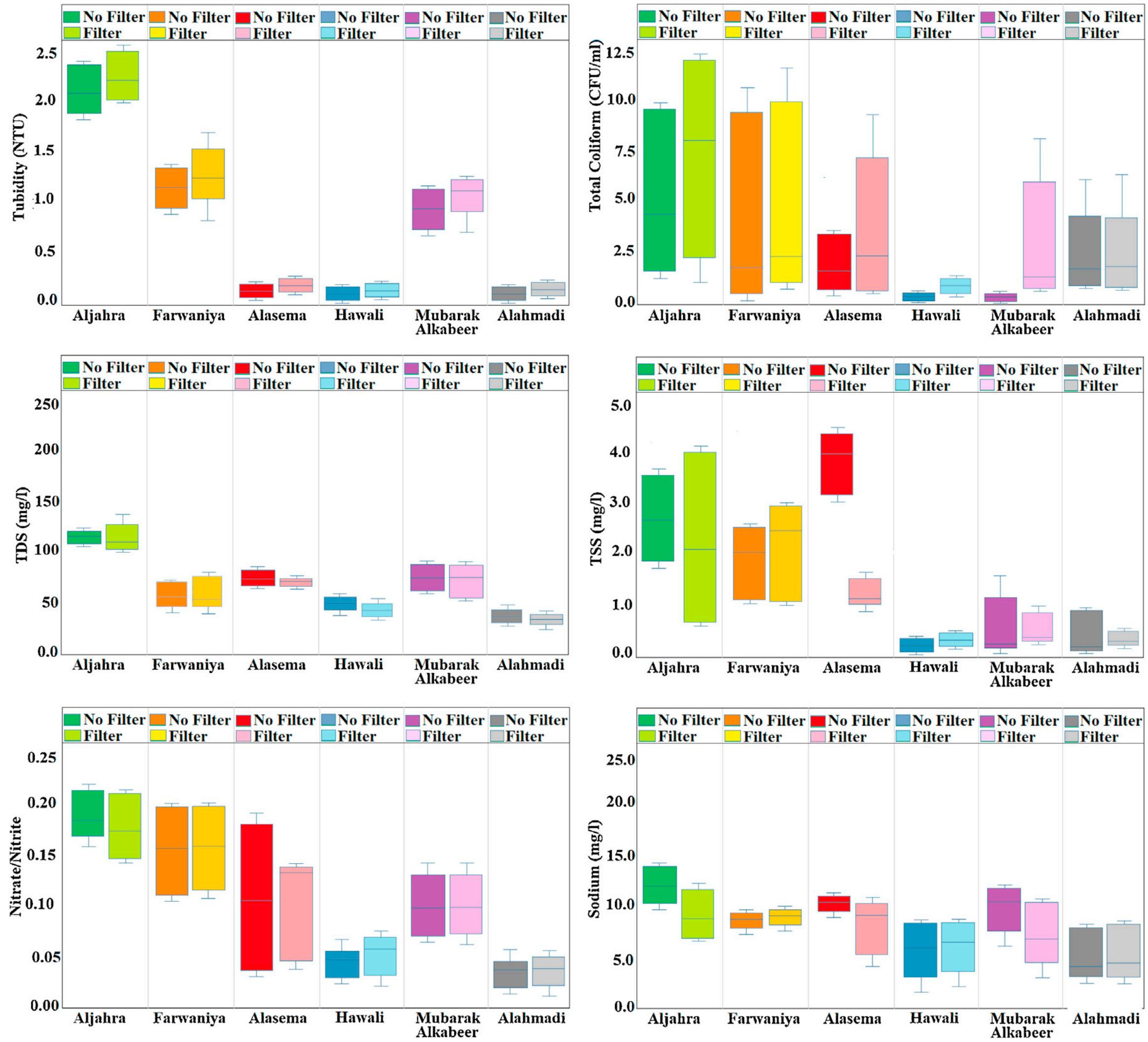

Fig. 3. Boxplot analysis for water parameters without and after using water filtration systems in Kuwaiti Governorates.

out the whole period. The level of total dissolved solids (TDS), nitrate/nitrite, pH, conductivity, and metals contents values were within the permissible levels of USA EPA (2001) and no statistical differences among filters and with and without filtration systems (p-value >0.05). Previous studies have also reported that household filters including membrane filter, candle ceramic filters, and pot ceramic were not competent for reducing TDS in water (Pérez-Vidal et al., 2016). This is possibly attributed to the small particle size of TDS (0.1 μm) and therefore they can easily penetrate most of household filters (e.g. the size of ceramic filters = 0.5−1 μm) (Lantagne, 2001).

Of all tested parameters, significant statistical differences were observed in TSS values (p-value = 0.00, F-value (5.15) >F-critical value (2.02)), turbidity values (p-value = 0.00, F-value (32.07) >F-critical value (2.02)), and coliforms population (p-value = 0.02, F-value (3.42) >F-critical value (2.03)). Removal efficiency of filters for TSS after 80 days monitoring is ordered in the following descending order: CF (89 %) = PF + CNBF (89 %) > CNRF (78 %) = SF (78 %) = CF + CNBF (78 %)> PF (44 %)> PF + CNBF + CNRF (44 %)> ROF (33 %). At 150 days, the performance of most water filters system configurations declined possibly as a result of progressive building up of contaminants on filter surfaces. Similar observation was also reported by Pérez-Vidal et al. (2016) where filtration removal efficiency dropped after 165 days due absence of cleaning procedures. Other studies have also indicated that these filters are highly susceptible to closure of filters components (Salvinelli and Elmore, 2015; Salvinelli et al., 2017). After regenerations of filters and/or changing water flowrates, the performance of water filters system improved as it is evident at 300 days. Similar observations were also noticed in turbidity and total coliform in terms of filters configurations, but with different magnitudes. At 300 days, all filtered water samples have turbidity less than maximum permissible level of 1 NTU (US EPA, 2001). Likewise, total coliforms varied from 7 to 18 CFU/mL over the 300 days with all filtration systems configurations, lower than USEPA limit of 500 CFU/mL (US EPA, 2001). Higher reduction efficiency of filter after cleaning was also ascribed to removal of biofilms formation, as some microorganisms species tend to stick on the solid part of the filters (Wingender and Flemming, 2011).

In terms of reduction performance, the single filter, especially ceramic filter (CF) achieved highest removal efficiency. This finding indeed shows that singular filters can efficiently remove water impurities and it contradicts people perception that installing multiple filtration systems can achieve highest removal efficiency of water impurities. Multiple filtration systems can undeniably suitable for untreated water, but not for treated fresh water delivered by government entity and underwent to several water treatments prior transport to residential houses. Overall, this study suggests that installing single filters can attain the required reduction efficiencies for TSS, turbidity, and

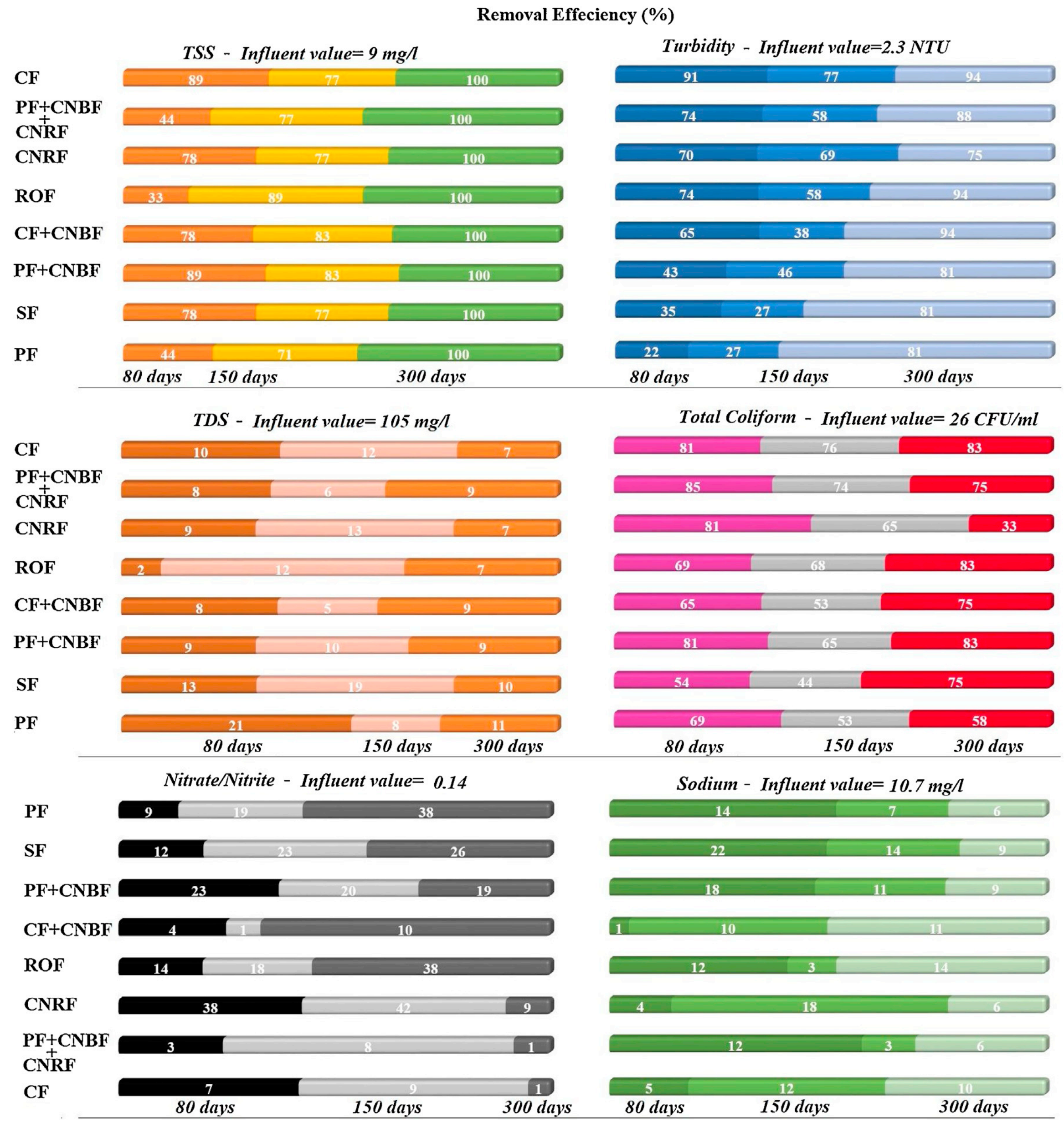

Fig. 4. Removal efficiency (%) of different filtration systems configurations for 10 continuous months.
Polyspun filter (PF), sand filter (SF), ceramic filter (CF), reverse osmosis filter (ROF), carbon block filter(CNBF), and carbon wrapped filter(CNRF).

microorganism if these household filters undergo periodic cleaning activities.

4. Conclusions

Lack of confidence in municipal water delivered to houses has induced the use of point-of-use water filters. The comprehensive investigation of physical, chemical, and microbiological parameters of water without and after using household filters in this study demonstrated that there should not be doubts or fears about the quality of water delivered through governmental network. The deterioration of water quality after filters could be plausibly due to lack of tank and filter cleaning and regenerations. Indeed, the results of this study revealed that 30 % of house owners failed to clean their tanks while 38 % could not remember the last time cleaned their tanks. Additionally, 38 % of house owners never clean their filters unless they feel change in taste or colors. Failing to clean tanks and filters would induce biofilms formation and point-of-use water filters could become reservoir of numerous types of chemical, physical, and microbial impurities. These contaminants eventually induce infectious diseases and non-infectious chronic diseases. In terms of performance, POU water filters are merely efficient for removing turbidity, total coliforms, and TSS in water. This study revealed that singular filters, especially polyspun filters, are enough to mitigated water impurities, but these household filters should undergo to periodic cleaning activities. To maintain clean water supply in houses, several measures should be taken in regular basis by house owners, water related government entity as well as POU supplier. House owners should either regularly clean their filters or replace old filtration system with those equipped with a warning device (e.g., alarm, light, etc.) that alert for malfunction or cleaning and maintenance of water filters and tanks. Alternatively, house owners may engage POU supplier to perform periodic monitoring surveillance and maintenance of water filters and tanks. POU suppliers should provide a manual to house owners that includes the specification of the filter, cleaning/regeneration protocols, and life-

Table 1
One Way ANOVA Test.

Property	Source of Variation	Sum of Squares	degrees of freedom	Means Square	F-value	P-value	F critical value
Conductivity	Between Groups	3194.071	8	399.259	0.156	0.996	2.022
	Within Groups	286351.929	112	2556.714			
	Total	289546.000	120				
Nitrite	Between Groups	0.001	8	0.000	0.618	0.762	2.021
	Within Groups	0.026	113	0.000			
	Total	0.027	121				
Nitrate/Nitrite	Between Groups	0.013	8	0.002	0.527	0.834	2.021
	Within Groups	0.361	113	0.003			
	Total	0.374	121				
pH	Between Groups	1.454	8	0.182	0.823	0.584	2.021
	Within Groups	24.951	113	0.221			
	Total	26.404	121				
TDS	Between Groups	943.287	8	117.911	0.120	0.998	2.021
	Within Groups	111224.715	113	984.290			
	Total	112168.002	121				
	Between Groups	378.497	8	47.312	5.162	0.000	2.029
TSS	Within Groups	953.261	104	9.166			
	Total	1331.758	112				
Turbidity	Between Groups	3140.514	8	392.564	32.076	0.000	2.021
	Within Groups	1395.208	114	12.239			
	Total	4535.722	122				
Coliforms	Between Groups	2656.761	8	332.095	3.422	0.002	2.036
	Within Groups	9315.229	96	97.034			
	Total	11971.990	104				
Metal-Calcium	Between Groups	178.091	8	22.261	0.886	0.531	2.021
	Within Groups	2840.364	113	25.136			
	Total	3018.454	121				
Metal-Copper	Between Groups	0.003	8	0.000	1.681	0.122	2.100
	Within Groups	0.014	59	0.000			
	Total	0.017	67				
Metal-Potassium	Between Groups	0.064	8	0.008	0.176	0.994	2.029
	Within Groups	4.754	104	0.046			
	Total	4.818	112				
Metal-Magnesium	Between Groups	8.572	8	1.071	0.981	0.455	2.021
	Within Groups	123.449	113	1.092			
	Total	132.020	121				
Metal-Sodium	Between Groups	18.365	8	2.296	0.117	0.998	2.021
	Within Groups	2210.385	113	19.561			
	Total	2228.750	121				

time of filters. Public awareness campaigns should be carried out in educational institutes, work places, and also in house by governments (e.g. ministry of electricity and water, environment public authority, and ministry of health). These campaigns should educate house owners about continuous monitoring of water filters, the best practices of cleaning, regeneration, and maintenance of water filters and tanks, and detrimental health impacts associated with water contaminants.

Author agreement

AA and MA designed the study and AA and KE performed the lab work. AA and MA analyzed the results and wrote the manuscript. All authors have approved the final article.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.psep.2020.06.051.

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