

## Water quality index analysis for portable and bottled waters

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### ABSTRACT

This research work aimed to investigate the degree of quality of tap and bottled waters available in Al-Madinah city through an experimental program comprising chemical, physical and biological tests. The study included examining the quality of the water supply network components such as taps, underground storage tanks and feeding pipes of the network. Filtration influence on the tap water was investigated by testing different water samples before and after the filtration process at different locations. The experiments also examined various bottled water brands sold in Al-Madinah. In addition, the impact of using the dispenser on the water quality of large bottled waters was studied. The water quality of two types of waters was compared by estimating water quality index (WQI). Results of this study revealed that the overall quality of the tap water is within standard values; however, deterioration occurs for the water through its journey in the water supply system. Results revealed that hardness and fluoride concentrations in bottled waters exhibited high values close to or more than allowable values of the standards. Furthermore, results confirmed that using the filter and dispenser decreased the water quality degree in the long run. Bottled waters showed a higher grade of WQI than tap water.

**Key words** | bottled water, drinking water, tap water, water quality, water quality index

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### INTRODUCTION

One of the essential elements of health security is safe and clean drinking water. It supports the development of the social and economic aspects (WHO 2011). The Kingdom of Saudi Arabia (KSA) is located within arid and semi-arid zones where water resources are very scarce. Portable drinking water, i.e. tap water, in Saudi Arabia comes from different resources including 50% from desalination; 40% from the extracting of groundwater; and 10% from surface water (NWC 2016). Many people in Al-Madinah governorate and the whole of Saudi Arabia do not use tap water as drinking water. Some of them treat tap water through home filtration equipment. These filters can remove specific organic chemicals while they may not remove nitrate, bacteria, or metals and they sometimes change the water properties. Other people prefer to drink bottled water, which is filled from natural springs or sometimes from tap

water with some treatment processes such as filtration and sterilization. This water may be stored in plastic bottles for a long time. These plastic bottles may leach out some harmful materials into the water, which may affect human health.

Desalination is increasingly being used as the main resource to provide drinking water for Saudi Arabia due to the scarcity of freshwater. Annually, 1.3 billion cubic meters of water is generated from desalination in Saudi Arabia, with 55% of plants located on the east coast and the remainder on the west coast. For Al-Madinah, three seawater desalination plants are located on the Red Sea coast, in the Yanbu Industrial City, approximately 230 km west of Al-Madinah. The desalination plant supplies freshwater to the residents of Al-Madinah region (NWC 2016). Chemical constituents such as calcium carbonate or richly mineral waters are mixed with desalinated waters to

improve the taste and reduce their corrosion impact on the distribution network as well as plumbing materials (WHO 2011). However, there are some concerns about the desalinated water on human health, especially if it is stored for a long time in plastic tanks in homes.

Some people use a home filter to treat the water due to health concerns and others use it just to improve the taste of their tap water. The home filter can eliminate some organic chemicals, including pesticide residues, however, it may not work effectively with other impurities such as nitrate, bacteria, or metals. The most common filters adopt activated carbon for removing such impurities. These types of filters are operative in removing lead and protozoan cysts and improving the taste of tap water. A water filter normally contains a screen with many microscopic pores. Decreasing the hole sizes of the filter increases the filter efficiency in removing impurities. Filter pores are measured in micro and nano scales. The Environmental Protection Agency (EPA) recommends that at least a one-micron filter is needed to eliminate *Cryptosporidium* (EPA 2005).

On the other hand, drinking bottled water is gaining in popularity in many countries, including Saudi Arabia, despite the enormously high price in comparison to tap water. The available natural resource of freshwater in Saudi Arabia is groundwater. Bottled water is filled mainly from this natural resource or sometimes from treated tap water. Groundwater has two principal features distinguishing it from surface water and these features influence its water quality. First, the slow velocity of water movement through the ground means that remaining times in groundwaters are generally much longer than in surface waters. Thus, as soon as a groundwater body has been polluted, the pollution could remain for decades or centuries due to the slow process of through-flushing. Second, there is a considerable degree of physical and chemical interdependence between the water and the containing material. The groundwater is a combination of water and soil, therefore, the properties of both the ground and the water, such as size and type of soil and flow features, are important. There is considerable possibility for the water quality to be altered by interaction between both elements (Chilton 1996). Therefore, due to concerns regarding public health, it is essential to evaluate the quality of bottled water due to its source and packing materials. Bottled water may become a source for supplying toxic trace metals; heavy

metals and radionuclide. The increase in the content of toxic chemicals, radionuclide, nitrites and nitrates in bottled water may cause a hazard influence to human health and lead to diseases such as human body malfunctions, chronic illnesses and cancer. Thus, there are significant dangers to humans, especially young people exposed to bottled water containing toxic elements and microbiological entities (Oyebog *et al.* 2012). Normally, different types of plastic contain different chemicals, indicated by the number inside the triangle of arrows on the bottom of the water bottle. In addition, there may also a possibility of some pathogenic bacteria growing due to long-time storage, along with favourable environmental conditions such as temperature and pH of the water, which may affect public health (Zamberlan da Silva *et al.* 2008).

In Riyadh, KSA, a study was carried out to determine the water quality of some commercial bottled waters from a chemical components aspect. The study concluded that most of the sample's quality level, about 82–88%, complied with the standards except for pH value, total dissolved solids (TDS),  $\text{SO}_4$  and F (Khater *et al.* 2014). In Al-Madinah, one study examined some types of bacteria in the drinking water network and their impact on human health (Al-Turk & Diab 2009). Ahmad & Bajahlan (2009) studied the comparison of water quality of desalinated tap water against bottled water in Yanbu city, KSA, and concluded that tap water supply is round the clock and is always fresh, while bottled water is not fresh because it is always packed a few months earlier than using it. They also stated that another major problem of using bottled water is the disposal of huge amounts of used plastic bottles. Toxic chemicals from used bottles may leach out into landfill sites and may pollute groundwater.

A water quality index (WQI) is a calculation method introducing a grade or score indicating the general quality of any type of water based on some certain parameters (Brown *et al.* 1970). Thus, WQI is considered as a means for explaining the raw water quality measurements and summarizes them in an understanding way to the public and decision makers. There are several water quality indices introduced by many researchers and environmental agencies, which are summarized elsewhere (GEMS 2007). These indexes include, for instance, the Canadian water quality index (CWQI), the arithmetic water quality index (AWQI) and the bottle water quality index (BWQI), which

were adopted herein to interpret the results and compare quality degrees of tap and bottled waters.

This research work aimed to investigate the quality degree of tap and bottled water available in Al-Madinah city. This was carried out through an experimental program including chemical, biological and physical studies for determining the water quality. The experiments included collecting tap water samples from different locations in Al-Madinah city and from different components of the water supply network such as feeding pipes, underground tanks and kitchen taps. In addition, the filtration influence on the tap water was examined by testing different water samples before and after the filtration process. The experiments also examined various bottled water brands sold in Al-Madinah. Furthermore, the impact on the water quality of using the dispenser on large bottled waters was studied. Finally, all these measurements were analysed and summarized by using WQI tools.

## METHODS

### Study area and sample collection

The Kingdom of Saudi Arabia is located within arid and semi-arid zones where water resources are very scarce. The Al-Madinah governorate is in the northwest of

Saudi Arabia as shown in Figure 1. The Al-Madinah governorate relies mainly on desalinated water coming from Yanbu city and some groundwater resources. It transfers the potable water into a distribution system, which consists of a pipeline system feeding an underground reservoir for each building and the latter feeds by a small pump and elevated storage tank on the top of each building (NWC 2016).

A brief knowledge about the storage process and construction materials used in this system may help in understanding the obtained results. The underground tanks are commonly constructed from cement bricks or reinforced concrete. They may be coated by cement paste and then painted with waterproof layers or covered by ceramic tiles. The elevated tanks are commonly made from PVC or HDPE materials and the external feeding pipes are normally ductile iron or PVC. In the past, the internal pipes in buildings were regularly made from ductile iron or copper and recently from PVC. The water is supplied from the water network to the underground tank 4 days a week and the other 3 days rely on the stored water in the tank.

This research work monitored the quality degree of desalinated tap and bottled waters in Al-Madinah city. Tap water samples were collected from 14 regions in the city as shown in Figure 1. For each region, three locations were examined. At each location, three samples from three



Figure 1 | Map for the studied area, Al-Madinah city in KSA and locations of water sample collection (Google maps).

positions in the network point were collected as follows: from the feeding pipe, underground storage tank and kitchen tap. The filtration influence on tap water was examined by collecting some water samples before and after filters from different locations. In addition, the most common brands of bottled water were bought in Al-Madinah. The study also examined the impact of using the dispenser with large bottled water by checking some water samples before and after dispensers from different locations. For collecting water samples from tap water and water dispensers, pre-cleaned, high-density polyethylene bottles were used. All samples were stored at 4 °C until analysis.

## Experiments and analysis

After sample collection, physical, chemical and biological tests were applied to each water sample. Table 1 presents the details of water quality parameters and their measurement techniques.

**Table 1** | Details of water quality parameters and their measurement techniques

Water quality	Parameter	Measurement technique
Physical	pH	pH meter probe
	Conductivity	Conductivity meter probe
	Turbidity	Turbidity meter probe
	Colour	Colour meter probe
	TDS	APHA method
Chemical	Alkalinity	Titration method
	Hardness	Test kits
	HCO <sub>3</sub> <sup>-</sup>	Titration method
	SO <sub>4</sub> <sup>2-</sup>	Turbidimetric method
	Cl <sup>-</sup>	Test kits
	NO <sub>3</sub> <sup>-</sup>	Test kits
	F <sup>-</sup>	Test kits
	Ca, Mg, Na, K, Fe	Inductively coupled plasma optical emission spectrometry (ICP-OES)
Cd, Ni, Cr, Mn, Cu, Zn, Ba, pb, As, Ag,	Inductively coupled plasma mass spectrometry (ICP-MS)	
Biological	Faecal coliform	Standard plate counts method – m-Endo agar
	Total coliform	Standard plate counts method – on eosin methylene blue (EMB)

## RESULTS AND DISCUSSION

### Water quality of all components of the water supply network

In this section, the water quality was tracked at several points in the water supply network inside the building at each location. As mentioned above, three samples from three positions in the network point were collected as follows: from the feeding pipe (i.e. water source), underground storage tank and kitchen tap. This is to determine the deterioration points of the water quality in the adopted system. Table 2 presents the results of physicochemical and biological tests for tap water. The following sections depict the physical, chemical and biological characteristics of these points and locations. Standard values for checking the water quality of collected samples were adopted from the WHO guidelines (WHO 2011).

### Physical properties

Turbidity and colour properties were investigated for five locations along the city at three positions in each building. WHO guidelines (WHO 2011) indicate turbidity and colour less than 5 NTU and 15 TCU respectively. The results shown in Table 2 revealed that both properties for all locations and positions are less than the specifications of water quality standards. One region showed a high level of turbidity but it was still within allowable values. There is a harmony between colour and turbidity results as they increase and decrease together. All samples showed a decrease for both water properties when transferring from a feeding pipe to a storage tank and kitchen tap. This is due to the settlement process for suspended impurities with time. However, one region, Alawaly, exhibited an increase in both properties. This is perhaps because the water collected extra impurities from inside the building pipe system. These collected impurities included chloride and iron because they exhibited a significant increase inside the water of the building, more than initial concentrations of the water source.

### Chemical properties

General chemical parameters, such as pH, TDS and hardness, for the different locations in the city are presented in Table 2.

**Table 2** | Physicochemical and biological analyses for tap water

Sample location/type	NO <sub>2</sub> <sup>-</sup> 3 mg/L	NO <sub>3</sub> <sup>-</sup> 50 mg/L	Cl <sup>-</sup> 250 mg/L	SO <sub>4</sub> <sup>2-</sup> 250 mg/L	F <sup>-</sup> 1.5–0.6 mg/L	Na <sup>+</sup> 200 mg/L	Fe <sup>2+</sup> 0.3 mg/L	pH 6.5–8.5	TDS 500 mg/L	Colour 15 TCU	Turb. 5 NTU	Hard. 100 mg/L	Cu 100 ppb	Zn 3,000 ppb	Cd, Ni, Cr, Mn, pb, As, Ag, Ba ppb	E. coli 0 (No.)	
																	Limit of SASO
Alashhel	Source	0.001	0.79	65	5.8	0.06	32	0.02	8.05	158	0.97	0.87	49	2	1.5	LLOQ	0
	U. Tank	0.004	1.01	69	9.4	0	24	0.02	7.98	159	0.54	0.44	65	2.1	0.45	LLOQ	0
	K. Tap	0.003	1.5	69	6.6	0	36	0.02	7.7	155	0.94	0.84	62	2.8	0.55	LLOQ	0
Algamea	Source	0.003	0.1	70	7.1	0.26	34	0.01	7.7	144	0.94	0.88	59	2.9	0.86	LLOQ	0
	U. Tank	0.003	0.13	66	7.2	0.25	34	0.01	7.38	146	0.92	0.82	61	2.9	0.86	LLOQ	0
	K. Tap	0.003	0.55	46	5.4	0.16	32.7	0.01	7.1	148	0.4	0.3	85	2	LLOQ	LLOQ	0
Alawaly	Source	0.004	1.3	58	6.1	0	31.2	0	7.59	132	0.75	0.65	52	3.2	1.3	LLOQ	0
	U. Tank	0.002	0.2	66	6.3	0.23	35.8	0.01	7.54	152	1.04	0.94	54	2.6	LLOQ	LLOQ	0
	K. Tap	0.001	0.13	71	5.4	0.24	31.1	0.14	8.04	144	1.16	1.06	52	3.1	LLOQ	LLOQ	0
Alsaih	Source	0.008	0.27	84	7.1	0.26	38.8	0.01	7.58	169	0.57	0.47	58	5.1	LLOQ	LLOQ	0
	U. Tank	0.008	0.52	82	6.7	0.06	36.4	0.02	7.74	170	0.52	0.42	53	LLOQ	LLOQ	LLOQ	0
	K. Tap	0.006	0.62	76	74	0.27	39.3	0.03	7.82	172	0.52	0.42	68	LLOQ	LLOQ	LLOQ	0
Alrabwa	Source	0.005	0.15	97	6.4	0.13	35	0.01	7.3	171	1.94	1.9	68	LLOQ	LLOQ	LLOQ	0
	U. Tank	0.004	0.15	97	6.7	0.13	35.5	0.01	7.3	170	1.94	1.84	67	LLOQ	LLOQ	LLOQ	0
	K. Tap	0.003	0.6	98	68.4	1.95	39	0.02	6.06	97	1.18	1.08	66	LLOQ	33	LLOQ	0
Alawaly-D	Tap	0.001	3	33.2	3.4	0.17	25.4	0.01	5.9	69.9	0.41	0.31	25	3.7	7.2	LLOQ	0
Central-D	Tap	0.005	0.8	88	6.9	3.27	35.1	0	7.47	163	0.95	0.85	77	2	1.5	LLOQ	0
Shwran	Tap	0.001	0.3	0	6.1	0.06	32	0.07	8.1	166.3	1.16	0.3	85	LLOQ	LLOQ	LLOQ	0
Fahed King	Tap	0.004	0.5	0	6.3	0.55	24	0.15	8.24	142.1	0.57	0.65	52	LLOQ	LLOQ	LLOQ	0
Westeren central	Tap	0.002	0.2	0	5.4	0.25	36	0.05	7.95	130	1.16	0.94	54	LLOQ	LLOQ	LLOQ	0
Deathea	Tap	0.001	0.1	0.1	7.1	0.36	34	0	8.1	180	1.04	0.47	52	LLOQ	LLOQ	LLOQ	0
Qabilteen	Tap	0.001	0.8	0.1	6.7	0.1	34	0.02	7.47	90	1.16	0.42	85	LLOQ	LLOQ	LLOQ	0
Alsheeb	Tap	0.008	0.6	0	74	0	32	0.6	8.1	102.3	0.57	0.3	52	LLOQ	LLOQ	LLOQ	0
Central	Tap	0.001	0.5	0.4	6.2	0.06	24	0.01	7.6	157	1.16	0.65	52	LLOQ	LLOQ	LLOQ	2
Alsaih	Tap	0.003	2.2	79	6	2	30.3	0.01	7.05	172.7	0.85	0.75	64	LLOQ	LLOQ	LLOQ	0
	Filter 1	0.004	1.3	61	4.2	2.25	37.5	0.02	7.24	82	0.76	0.66	75	LLOQ	LLOQ	LLOQ	0
Alrabwa	Tap	0.002	0.9	64	5.7	1.62	33.8	0.13	7.08	94	0.75	0.65	66	LLOQ	LLOQ	LLOQ	0
	Filter 2	0.006	0.6	77	5.2	1.45	30.9	0.03	7.17	75	0.84	0.74	85	LLOQ	LLOQ	LLOQ	8
Algamea	Tap	0.004	0.7	82	21.2	1.58	40.7	0.05	7.05	78	0.77	0.67	76	LLOQ	LLOQ	LLOQ	0
	Filter 3	0.002	13	69	22.5	2.57	32.6	0.06	7.27	74	0.75	0.65	84	LLOQ	LLOQ	LLOQ	4

LLOQ, Lower limit of quantitation.

The results showed that pH values are within standard values, ranging between 6.5 and 8.5. TDS and hardness results also fell within the permissible values of 500 and 200 mg/L respectively. There was no significant change in TDS values for the three positions in each location, while there was a remarkable change in pH and hardness values for some locations. For instance, Algama location showed a significant decrease in pH, chloride and fluoride, accompanied with a great increase in the hardness value for tap water, around 40% more than that in the feeding water. Perhaps the decrease in pH was due to the production of soluble salts formed by metal oxides generated from pipe corrosion, making the chlorine and fluoride react. On the other hand, an increased hardness value resulted from the water calcium ions from cement used in constructing the underground storage tank.

Several anions and cations were examined in the collected samples. The results showed that all anions and cations were below the acceptable levels of standards, as shown in [Figure 2](#). In addition, no significant change was found among the three positions except at Alawaly location, where there was a sudden increase in the iron level inside the building system. This agrees with the results shown previously about the increase in turbidity inside the system for this location. This refers to the possibility of pipe corrosion because the region has very old buildings and a steel water system inside buildings. For heavy metals, results showed very low concentrations in all locations and all values fell with the standard levels, as shown in [Table 2](#).

### Biological properties

Faecal coliform and total coliform were examined in all collected samples. [Table 2](#) presents the biological analysis results. The results of all samples showed zero bacteria. Nevertheless, one sample from the central region contained two bacteria which means it is unsafe water. However, the water in this location is not used for drinking purposes.

### Overall tap water quality

This section describes the overall water quality for all regions in the city. These results are for tap water only, collected from 14 regions. [Figure 3](#) presents some examples of water quality parameters for the 14 regions. Results showed

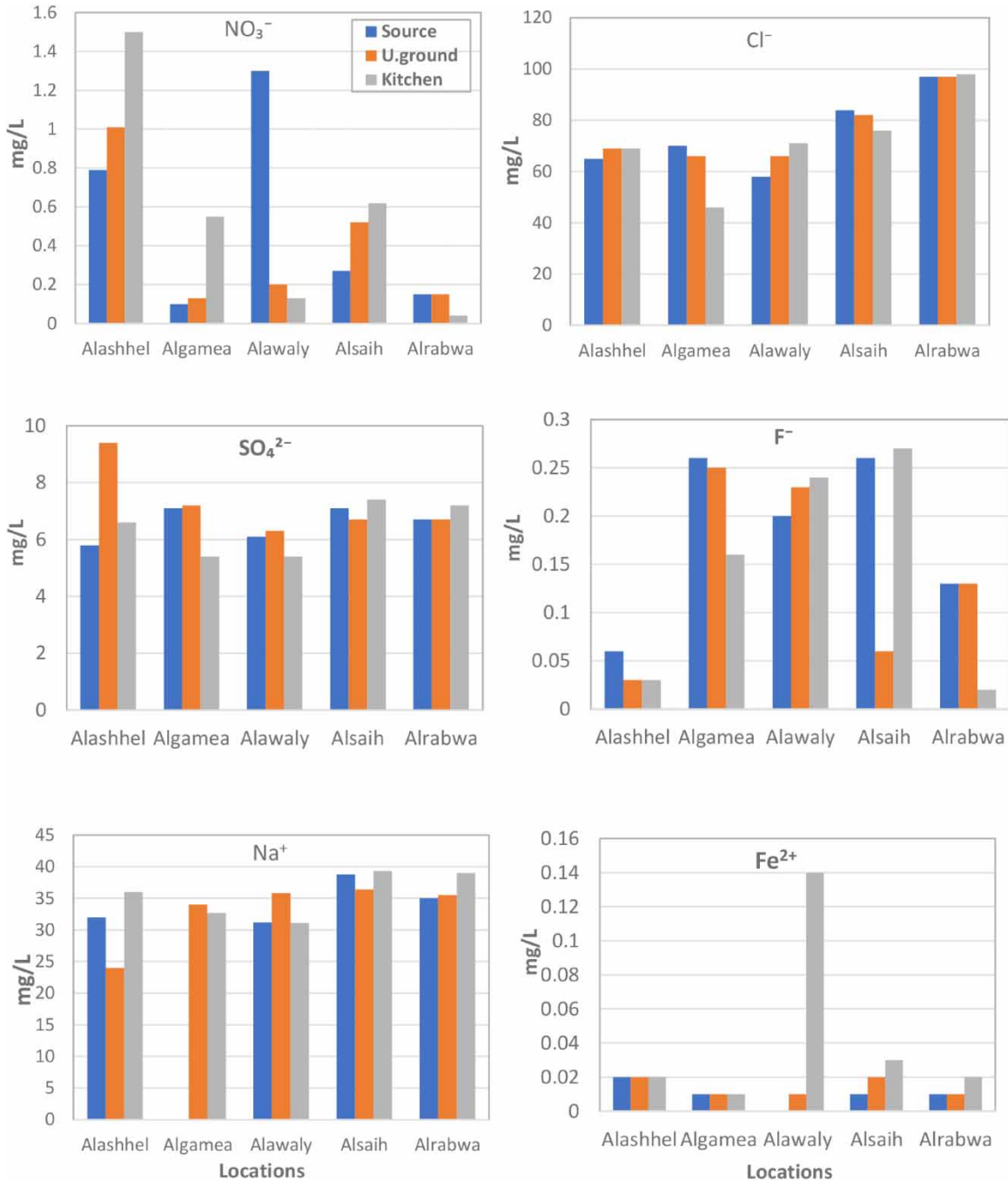
that all measured parameters fell within standard values. However, the results showed an increase in fluoride in the Central-D region above the specifications. [Alabdulaaly et al. \(2013\)](#) reported that the natural water in Al-Madinah has a generally low fluoride element, thus it is regularly added into water. Perhaps its dosage is not added accurately. In addition, a significant increase above permissible values was noted in the iron level in Alsheaba region, as seen in [Figure 3](#). This is due to pipe corrosion because the region has very old buildings and relies on an old steel pipe system.

From the results discussed in this section and in previous ones, the overall quality of the tap water is within standard values. However, deterioration occurs to the water though its journey in the whole water supply system. The water starts with high quality and reaches the customers at a lower level of quality. This deterioration may be due to using very old water pipe supply systems and relying on feeding buildings through isolated underground storage tanks.

### Effects of using a filter on tap water quality

Many people in Al-Madinah city do not drink directly from tap water. They prefer to treat tap water through home filtration equipment. Herein, the impacts of using filters was examined. Three sample batches were collected from three different locations in the city using different brands of filters. Samples were collected before and after filters. [Figure 4](#) presents some physical and chemical properties of tap water before and after filters at three different locations. The results showed a slight increase for pH values after using the three filters, i.e. changed from 7.05 to 7.28, associated with a slight increase in hardness values by almost 10 mg/L and a decrease of TDS values. Iron concentrations increased when using filters 1 and 3 while a significant decrease occurred when using filter 2. Filters 1 and 3 decreased turbidity, colour and chloride while filter 2 slightly increased them. In addition, nitrate, sulphate and fluoride were almost the same or slightly decreased while filter 3 increased them. In fact, the tested filters showed either a slight decrease in concentrations of the chemical elements or an increase in them. This is perhaps because the filters are not regularly cleaned and maintained. The most concerning and alarming problem are the biological test results which revealed that bacteria





**Figure 2** | Anions and cations of tap water at different locations and components of Al-Madinah water supply network.

were found in the output water of filters 2 and 3. The same results were reported elsewhere (Nriagu *et al.* 2018). To sum up, using the filter can be considered as a double-edged

sword; it can help in removing impurities in the first stage, but after a while it becomes a source of pollutant and a medium for growing bacteria.

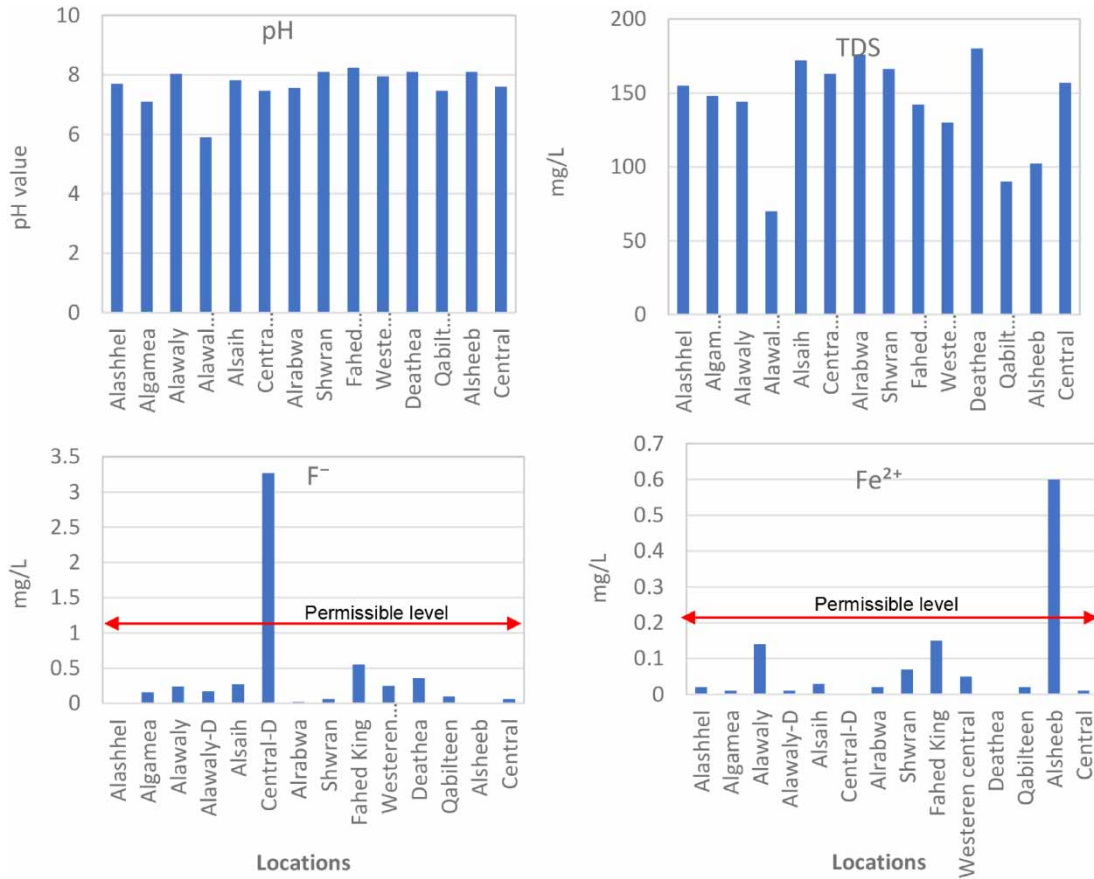


Figure 3 | Some parameters of overall tap water quality in the Al-Madinah water supply network.

### Water quality of bottled waters

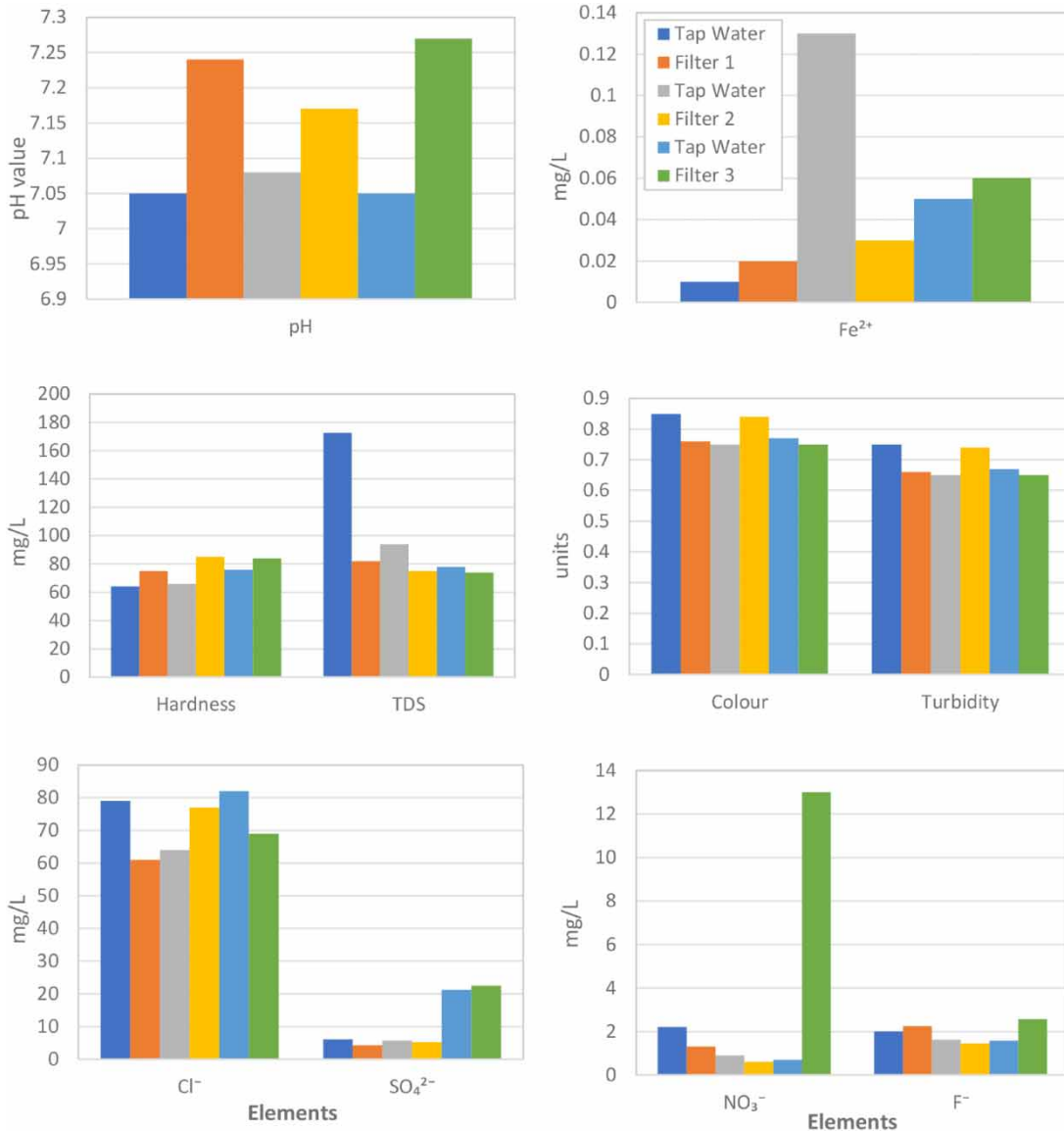
The examined water bottles were purchased from the most common bottled water brands sold in Al-Madinah city. The same parameters as studied for tap water were examined for these brands. The study also investigated the impact on the water quality when using the water dispenser with the large bottled water. Thus, water samples were collected before and after using dispensers from different locations in the city. Table 3 presents the results of physicochemical and biological tests for bottled water.

### Physicochemical and biological properties of bottled water

The results of the physicochemical and biological properties for the four most common brands are shown in Table 3.

The results showed that both turbidity and colour properties for all brands are less than the specifications of water quality standards. Furthermore, the results of general chemical parameters such as pH, TDS and hardness for the different brands of the bottled water showed all properties were within standard values, however, hardness values exhibited high values close to the borderline of the allowable values, see brand 3 results. Figure 5 shows the results of some anions and cations in the bottled waters. The results revealed that all these chemical elements were within the standards of drinking water quality. Nevertheless, the results showed high concentrations for the fluoride element, close to the specification border of 1.5 mg/l. For example, the fluoride element for brand 3 was 1.52 mg/L. It is worth mentioning that the chemical analysis results of the examined bottled waters showed an inaccuracy in the provided information on the bottle labels. For example, brand 2 reported hardness and





**Figure 4** | Physical and chemical properties of tap water before and after filters at different locations in Al-Madinah city.

chloride as 65 and 17 mg/L, respectively, however, the results showed that they are 33 and 88 mg/L respectively. Brand 3 reported hardness as 84 mg/L and the results showed it to be 200 mg/L. Other examples are presented in Figure 6. There are more examples of inaccuracies in the other properties, however they are not presented herein. For tracking faecal coliform and total coliform in the bottled waters, the results of all samples showed zero bacteria.

### Effects of using the dispenser on bottled water quality

In this section, the influence of using the dispenser on the water quality of large bottled water (20 L) was investigated. Water samples from three dispensers at different locations were examined. Table 3 presents the results of physicochemical and biological properties of the bottled water before and after using the dispenser. Almost all measured chemical elements showed decreases in

Table 3 | Physicochemical and biological analyses for bottled water

Sample location/type Limit of SASO	NO <sub>2</sub> 3 mg/L	NO <sub>3</sub> 50 mg/L	Cl <sup>-</sup> 250 mg/L	SO <sub>4</sub> <sup>2-</sup> 250 mg/L	F <sup>-</sup> 1.5–0.6 mg/L	Na <sup>+</sup> 200 mg/L	Fe <sup>2+</sup> 0.3 mg/L	pH 6.5–8.5	TDS 500 mg/L	Colour 15 TCU	Turb. 5 NTU	Hard. 100 mg/L	Cu 100 ppb	Zn 3,000 ppb	Cd, Ni, Cr, Mn, pb, As, Ag, Ba ppb	E. coli 0 (No.)
Brand 1	0.003	1.1	50	8.1	1.15	7.8	0.03	7.66	75	1.66	1.56	51	LLOQ	LLOQ	LLOQ	0
Brand 2	0.003	0.18	33	49	0.88	1	0	6.59	106	0.58	0.48	88	LLOQ	LLOQ	LLOQ	0
Brand 3	0.005	1.4	52	28.3	1.53	5.2	0	6.84	108	0.95	0.85	200	LLOQ	LLOQ	LLOQ	0
Brand 4	0	1	55	66.8	1.04	2.6	0.02	6.5	92	0.65	0.55	172	LLOQ	LLOQ	LLOQ	0
Big Bottle 1	0.003	1.1	50	8.1	1.15	7.8	0.03	7.66	75	1.66	1.56	51	LLOQ	LLOQ	LLOQ	0
Dispenser 1	0.003	0.9	38	8.3	0.89	8.4	0.03	7.54	51	0.86	0.76	49	LLOQ	LLOQ	LLOQ	6
Big Bottle 2	0.003	1.4	39	8.1	0.8	6.5	0.03	7.92	56	3.10	1.75	43	LLOQ	LLOQ	LLOQ	0
Dispenser 2	0.003	1.2	32	8.3	0.71	7.4	0.03	7.84	28	2.83	0.96	41	LLOQ	LLOQ	LLOQ	2
Big Bottle 3	0.002	0.7	95	68.4	2.23	8.5	0.02	6.22	106	0.61	0.51	77	LLOQ	LLOQ	LLOQ	0
Dispenser 3	0.001	0.4	88	65	2.34	10	0.02	6.1	121	0.96	0.59	70	LLOQ	LLOQ	LLOQ	0

LLOQ, The lower limit of quantitation.

concentrations after using the dispenser as shown in the table.

A significant decrease occurred in chloride, TDS, turbidity and colour. This may be due to the impact of the settlement process for the suspended impurities. It appears that the dispenser improves the chemical quality of the bottled water. However, in contrast, the biological test showed adverse results. The counting test for faecal coliform and total coliform in the bottled waters showed 2–6 bacteria for water after using the dispenser. Thus, using a dispenser changes the water quality status to unsafe because it allows bacteria growth. Perhaps this occurs due to the air-tight dumping area inside the dispenser, which activates the growth of bacteria, or maybe during set-up when holding the top of the bottles with unwashed hands. It is a crucial matter to manufacturers of these types of large bottled water to set up a safe procedure for use with the dispensers. In addition, it is recommended for users to regularly clean the dispensers by rinsing internal components of the dispensers with antibacterial or very hot water to make sure the bacteria is killed.

### Water quality of tap water versus bottled waters

In a trial to compare the water quality of the tap and bottled waters in Al-Madinah city, an average of the results of all samples was estimated as a single number, as shown in Figure 7. The results showed that pH in tap water is higher than bottled water and the latter exhibited very low pH values, close to the minimum acceptable border of standards, i.e. 6.5. Furthermore, it is worth noting that the turbidity and colour values for tap water is less than those of bottled water, which implies that the tap water has fewer suspended impurities. Chloride is higher in tap water than bottled water but is the opposite in the case of fluoride. This also indicates the water quality of tap water. For sulphate and nitrate, bottled water exhibited higher concentrations than those of tap water. In addition, iron concentration in the tap water is two-fold in comparison to bottled water. In spite of this fact, both types are within standard values but some points refer to the quality of the tap water rather than bottled water, while others reveal the opposite. In fact, it is crucial to find a number to determine the best water quality in both types. This will be

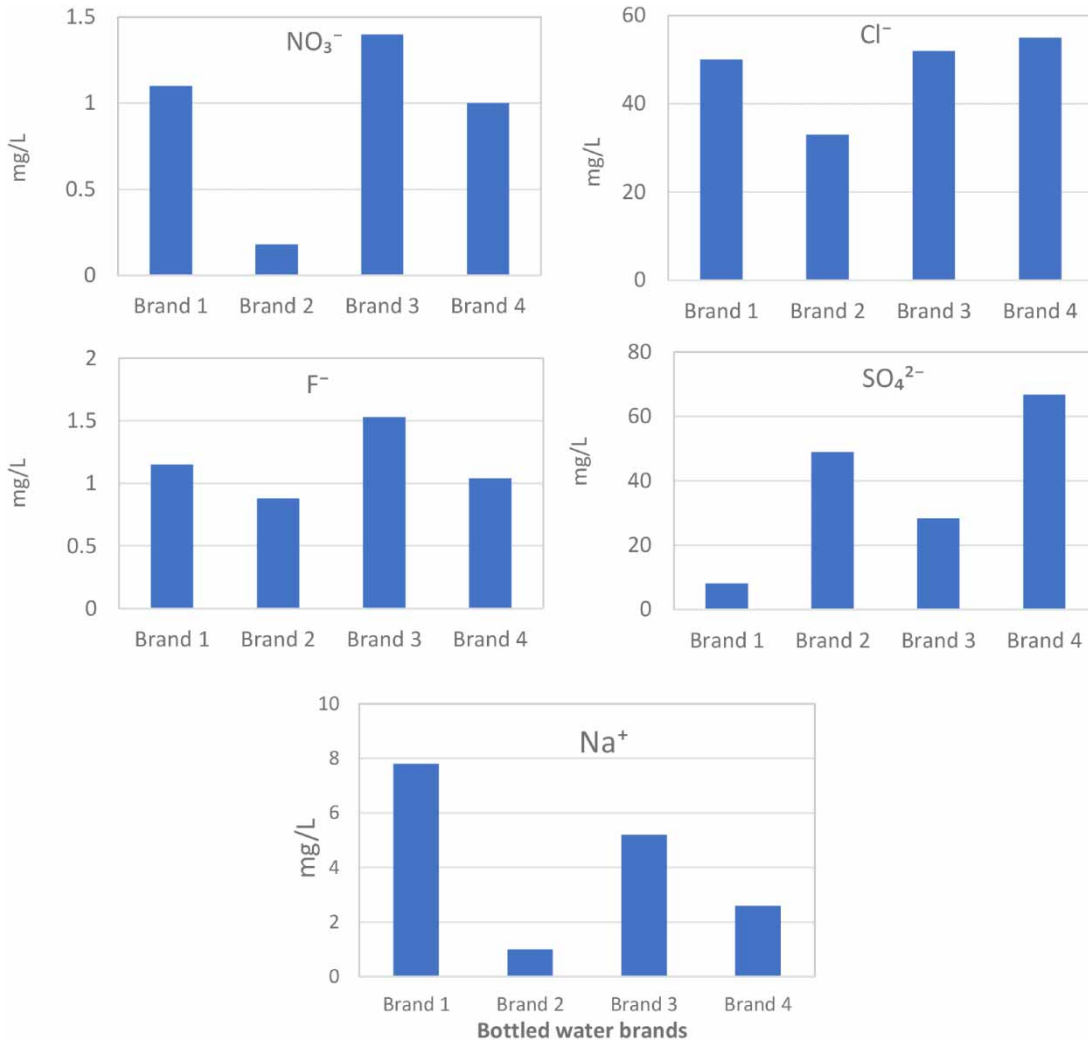


Figure 5 | Anions and cations of common brands of bottled water in Al-Madinah city.

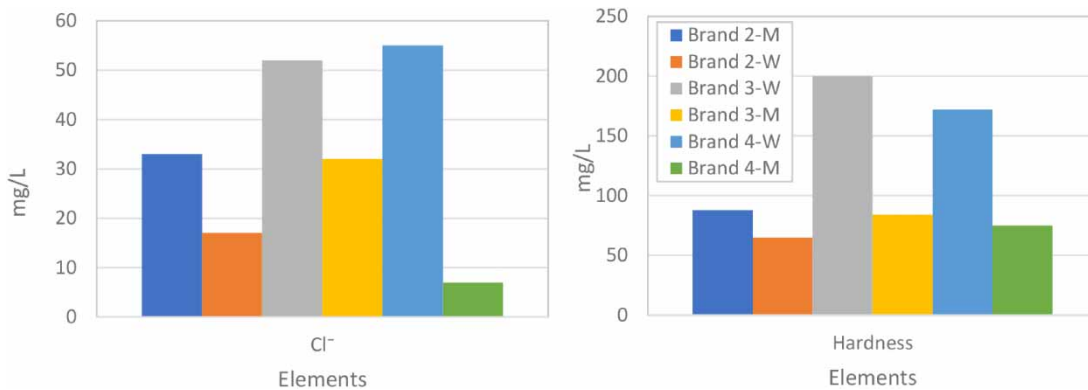
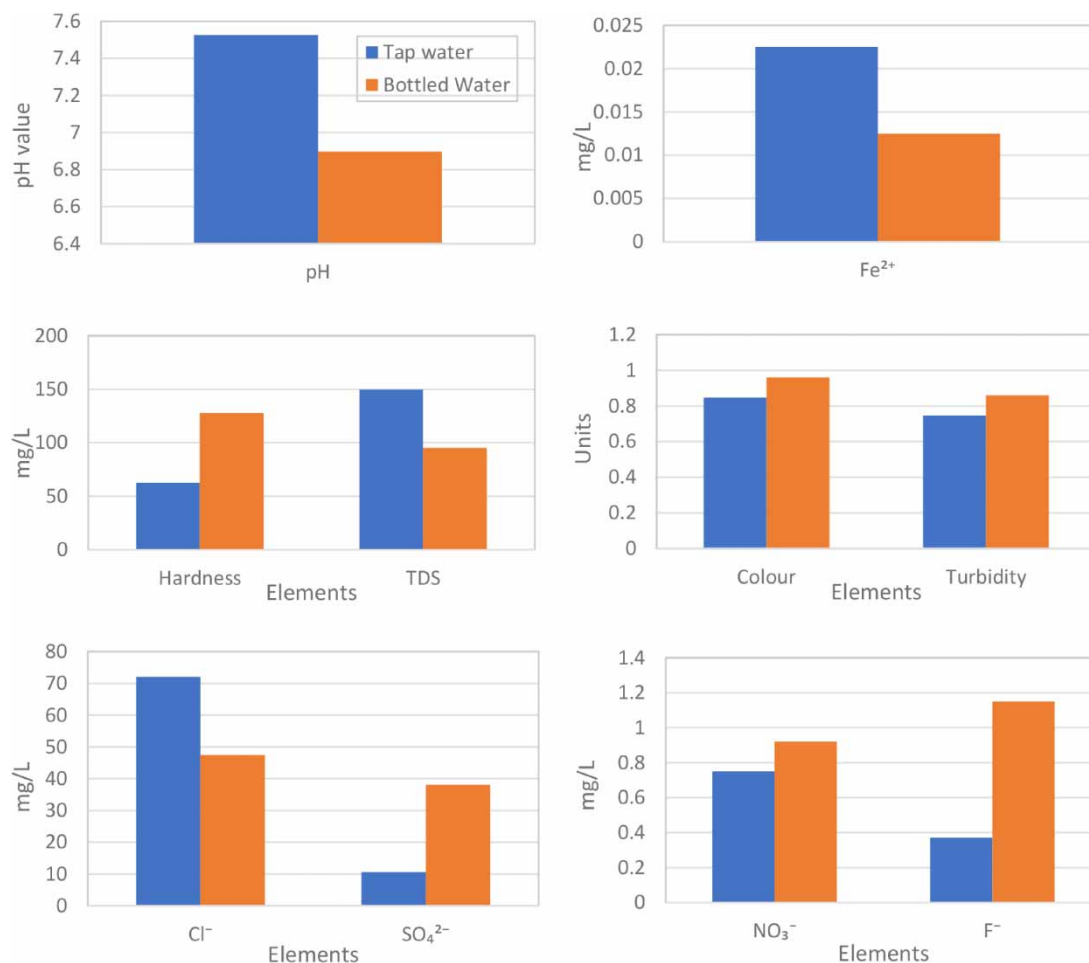


Figure 6 | A comparison for some element concentrations between measured values (M) with written values (W) on bottled waters.



**Figure 7** | Physical and chemical properties of tap water versus bottled water in Al-Madinah city.

discussed in the following section regarding using water quality indexes.

### Water quality index

A WQI delivers a single number or grade that refers to the overall water quality of any location at a certain time, based on at least four different water quality parameters (Brown *et al.* 1970). WQI is a tool for summarizing water quality data to be reported in a simple and understandable way to decision makers and the public. The WQI indicates the quality of drinking water by a specific number. Several water quality indices have been introduced by many researchers and environmental agencies (GEMS 2007).

The CWQI is the most comprehensive and popular among these indices. It calculates three factors (F1, F2, and F3), measuring the scope, frequency, and amplitude, respectively, of water quality exceedances. Factor F1 characterizes the extent of water quality guideline standards by checking the number of failed variables against the total number of variables. F2 measures the percentage of individual tests that failed. F3 indicates failed tests which do not meet their objectives. These three factors are associated into one formula to produce one score as shown in the following equation (CCME 2001). The calculations of this equation yield a grade between 0 and 100. The higher the grade refers to the higher the quality of water. More details about this index and its validity are described elsewhere (CCME 2001; Davies 2006;

GEMS 2007).

$$WQI = 100 - \left[ \frac{\sqrt{(F1 + F2 + F3)}}{1.723} \right] \quad (1)$$

where:

$$F1 = \left( \frac{\text{Number of Failed Variables}}{\text{Total Number of Variables}} \right) \times 100;$$

$$F2 = \left( \frac{\text{Number of Failed Tests}}{\text{Total Number of Tests}} \right) \times 100;$$

$$F3 = \left( \frac{\text{NSE}}{0.01\text{NSE} + 0.01} \right) \times 100$$

Normalized Sum of Excursions (NSE)

$$= \left( \frac{\text{Excursions}}{\text{Total Number of Tests}} \right) \times 100$$

Failed tests greater than objective:

$$\text{Excursions} = \left( \frac{\text{Failed Test Value}}{\text{Objective}} \right) - 1$$

Failed tests less than objective:

$$\text{Excursions} = \left( \frac{\text{Objective}}{\text{Failed Test Value}} \right) - 1$$

This CWQI was adopted to check the overall quality of Al-Madinah city. It was applied on the observed parameters of 14 regions in the city. At least eight water quality parameters were adopted for each location. The results of the calculations of CWQI and its factors for these regions are presented in Table 4. The results of CWQI calculations showed that the water quality of many regions was between good and excellent grade. Only one region showed a fair grade. A summary of these grades is presented in Figure 8.

CWQI was used to compare tap and bottled waters in Al-Madinah city. The overall CWQI for tap water was calculated based on all available parameters of all regions to produce one number describing the water quality of water supply system in the city. In the same manner, a single number for all tested brands of bottled water was calculated. Figure 9 presents these calculations. The results showed that the overall CWQI for tap and bottled waters were 78 'fair' and 92 'good' grades, respectively. According to CCME (2011), Grade 'good' means water quality is protected with

Table 4 | CWQI calculations for the tap water in different locations in Al-Madinah city

Region/ network	CWQI	Category	F1 (scope)	F2 (frequency)	F3 (amplitude)
Alashhel	100	Excellent	0	0	0
Algamea	100	Excellent	0	0	0
Alawaly	92	Good	13	6	0
Alawaly-D	88	Good	14	14	1
Alsaih	100	Excellent	0	0	0
Central-D	92	Good	13	6	3
Alrabwa	91	Good	13	6	7
Shwran	100	Excellent	0	0	0
Fahed King	100	Excellent	0	0	0
Western central	100	Excellent	0	0	0
Deathea	100	Excellent	0	0	0
Qabilteen	100	Excellent	0	0	0
Alsheebea	77	Fair	25	25	20
Central	100	Excellent	0	0	0

CWQI grades: Excellent (95–100); Good (80–94); Fair (65–79); Marginal (45–59); Poor (0–44).

only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels, while grade 'fair' means water quality is usually safe but occasionally vulnerable; conditions sometimes are at undesirable levels. Thus, the overall quality of all water types is acceptable and healthy. It is worth observing that the overall index of the tap water of the city is less than indexes of water quality in many individual locations in the same city. This is due to the impact of failures in a few parameters in some individual locations. The sensitivity to the number and type of parameters is reported by Davies (2006) as a minor weakness of the CWQI.

Another index estimating the water quality using the weighted arithmetic method can be abbreviated as AWQI. In this index, the quality rating scale for each parameter,  $qi$ , was calculated by dividing its concentration in each water sample by its respective standard and the result was multiplied by 100. Relative weight ( $Wi$ ) was calculated by a value inversely proportional to the recommended standard value of the corresponding parameter. The overall AWQI was calculated by aggregating the quality rating ( $qi$ ) with unit weight ( $Wi$ ) linearly as shown in Equation (2). Details of this index are described elsewhere (Yisa &

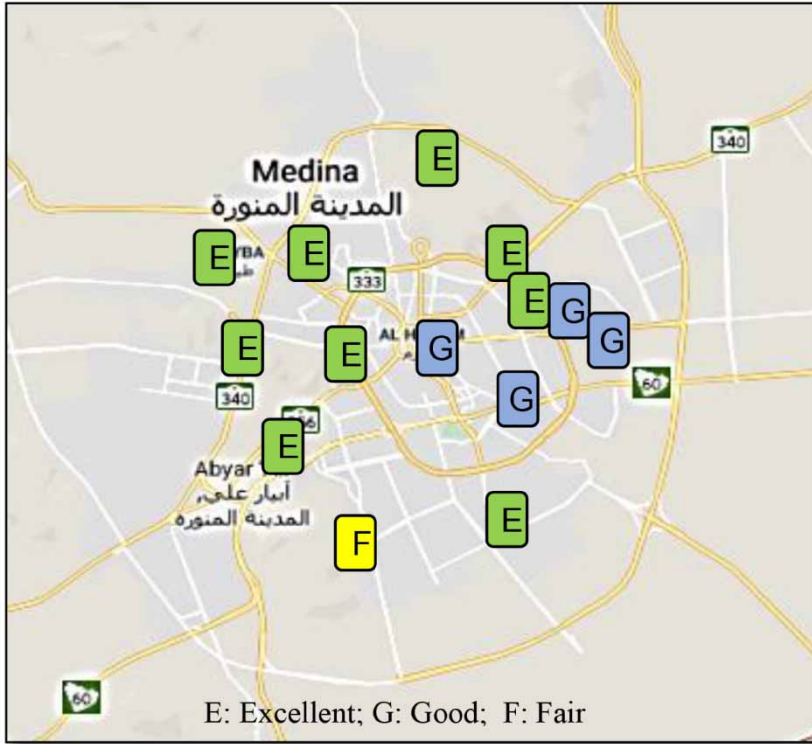


Figure 8 | A map showing the summary of CWQI grades for all regions in Al-Madinah city.

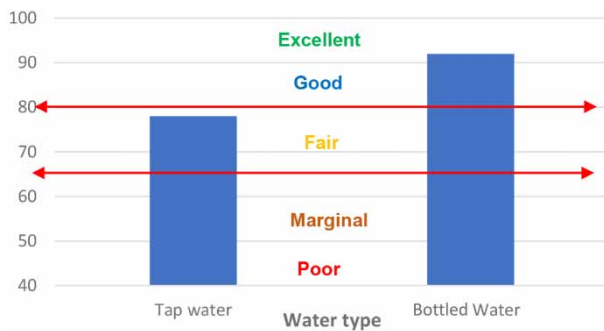


Figure 9 | Overall CWQI calculations for tap and bottled waters in Al-Madinah city.

Jimoh 2010; Tyagi et al. 2014).

$$AWQI = \left[ \frac{\sum Wi * qi}{\sum Wi} \right] \tag{2}$$

Water quality classification based on this index adopted the score of less than 50 as excellent water quality level; good quality for values ranged between 50 and 100; and

poor for values for between 100 and 200. In this study, all measured parameters were averaged for the tap and bottled waters and the overall AWQI was calculated for both types of water. The results of applying this method showed index values for tap and bottled water as 28.76 and 28.70 respectively. The results confirmed the excellent quality for both sources of drinking water as they obtained an index value less than 50. It is worth noting that both values of tap and bottled waters are very close. This may be due to the weak sensitivity of this index in comparison to applying the previous CWQI presented by CCME (2011) because the latter showed two different categories for the two types of water.

A water quality index applied only for the bottled water called BWQI was presented by Tsakiris (2016). The index relies on seven parameters, namely, *Escherichia coli* counting, pH value, nitrates (NO<sub>3</sub>), nitrites (NO<sub>2</sub>), chloride (Cl<sup>-</sup>), sulphates (SO<sub>4</sub>) and electrical conductivity (EC) at 20 °C. The equation and details of BWQI index are described elsewhere (Tsakiris 2016; Tsakiris et al. 2017). The BWQI values are between 0 and 1 and the score 0 means bottled water is



at unacceptable quality. Scores ranged from 0.7 to 0.85 reflected good water quality while scores above 0.85 indicate excellent water quality. BWQI was used in this study to examine the same adopted bottled waters. The results of applying this index showed that BWQIs for the four brands were 0.93, 0.92, 0.90 and 0.87, respectively. All bottled water brands are in the excellent score according to the limits described above. These results are very close to the previous ones obtained by CWQI.

## CONCLUSIONS

- The results of this study revealed that the overall quality of the tap water is within standards values; however, deterioration occurs to the water through its journey in the whole water supply system. This deterioration may be due to the old age of the pipe supply system and reliance of providing water into the building through isolated underground storage tanks.
- The results showed that all properties of bottled waters are within standard values, however, some properties such as hardness and fluoride concentrations exhibited high values close to the border line of the specification.
- Using a filter with tap water can be considered a double-edged sword; it can help in removing impurities in the first instance but after a while it changes to a source of pollutants and a media for growing bacteria.
- Using a dispenser increased the chemical water quality by removing some suspended impurities due to the settlement process; however, it decreased the biological quality aspect by allowing some bacteria to grow.
- It is a crucial matter for manufacturers of the large bottled water to set up a safe procedure for using these bottles with dispensers. In addition, it is recommended for users to regularly clean the dispenser to ensure the removal of these bacteria.
- Both types of water are within standard values but some points refer to the quality of the tap water rather than bottled water while others revealed the opposite. Perhaps it is crucial to find a number determining the best water quality between both types, such as WQI.
- The results of WQI calculations for tap water showed that the water quality of many regions was between fair and excellent grade.

- Overall, the Canadian WQI for tap and bottled waters were 78 fair grade and 92 good grade, respectively, while AWQI showed scores of 28.76 and 28.7 respectively, which refers to excellent water quality for both types.

## ACKNOWLEDGEMENTS

The author would like to acknowledge the research deanship, the Islamic University in Madinah, KSA, for supporting this research work under the project number 40/86. The author also extends his thanks to the Science of College at Islamic University and Al-Madinah Amana labs for their help and support in sample analyses.

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First received 1 January 2020; accepted in revised form 24 March 2020. Available online 11 May 2020