

# Chemical Quality of Bottled Waters: A Review

Malwina Diduch, Żaneta Polkowska, and Jacek Namieśnik

**Abstract:** Bottled water has become very popular for quenching thirst and as a dietary (mineral) supplement. The plethora of natural mineral waters precludes any unequivocal system of classification, which makes it difficult for the consumer to choose a water with properties that suits him/her exactly. The ever-increasing popularity of bottled waters means that it is of the utmost importance to determine not only their mineral content, but above all, the content of possible contaminants, especially organic ones. In this respect bottled waters are a special case, because apart from organic contamination from the environment, the water may become secondarily contaminated as a result of its being improperly transported and stored. Pesticides, volatile organic compounds, and carbonyl compounds have been detected in samples of bottled water. This overview shows the available published information on levels of inorganic constituents and organic contaminants in samples of bottled water in the context of sample preparation procedures and analytical techniques.

**Keywords:** analytical techniques bottled water, chemical composition, classification

## Introduction

Just 15 to 20 y ago, water in a plastic bottle was not a regular item on many consumers' shopping lists. Today, however, thousands of millions of liters of water are sold in all types of packaging and containers. The mineral water market is the most dynamically expanding branch of the nonalcoholic beverage sector (Bong and others 2009). There are many reasons for this ever-increasing popularity of bottled water. For example, success can be attributed to effective marketing strategies. Drinking water out of a bottle not only quenches one's thirst, but it is equated with a hygienic lifestyle, fitness, health, and good looks as well (de Beaufort 2007). The sales campaigns of food conglomerates have discouraged people from drinking municipal water, even though it is subjected to very much the same rigorous quality requirements as bottled water.

Bottled water is also frequently chosen as an alternative to municipal water for reasons of taste and smell, because in most countries of the world water cannot be disinfected by chemical means. Bottled water, in contrast, can be bought not only in every food shop but also at most service points. The demand for bottled water is completely independent of the supply of municipal water, which is frequently of identical, if not even higher, quality. Suffice it to say that sales of bottled water are greatest in highly developed countries, where tap water is of high and even very high quality. Against this, a single bottle of *Evian* water costs as much as it would to fill it with municipal water once a day for more than 10 years! On average, a liter of bottled water is from 250 to 600 times more costly than a liter of tap water.

A serious environmental problem connected with the constantly rising consumption of bottled water is the bottles in which it is sold. Because of their immense numbers, they are littering the world all over and have become the most troublesome item of rubbish at the present time (Coelho and others 2011). Most

water bottles are produced from polyethylene terephthalate (PET), which in itself is an innocuous substance and is recyclable but not biodegradable (Hansen and Pergantis 2006). However, only 23% of PET bottles are recycled in the USA, and approximately 17% in Poland (Benefits of Recycling). To produce 38 thousand million plastic containers for bottled water consumed in the USA in 2006 alone, one and a half million barrels of crude oil was needed, not to mention the fuel required for transportation around the country.

## Classification of mineral waters

The very concept of "mineral water" was first defined, at the International Balneological Congress at Nauheim, Germany, in 1911, as water containing at least 1000 mg of dissolved mineral constituents per liter, and this norm was accepted by all the countries represented at the Congress. Over the next 80 y or so this definition was changed many times, resulting in waters with a lower mineral content also being labeled "mineral"; by 1990 the acceptable level had fallen to 200 mg/L [PL-BN]. Consequently, the market became flooded with pseudo-mineral waters. In spite of disclaimers in various directives playing down this reduction in mineral content, most bottled waters are still falsely labeled "mineral waters"; in fact, only about 30 of the more than 200 brands on the market in Poland deserve this name.

To a very great extent, the composition of subterranean water depends on the type and structure of the rocks with which it comes into contact. The multifarious minerals forming the Earth's crust, as well as the various hydrogeochemical processes (sorption, oxidation and reduction, leaching, weathering, hydrolysis) and physical parameters (temperature, pressure) affecting these processes, have given rise to an immense diversity of mineral waters.

This makes it impossible to draw up a uniform system of classification, even if the only criterion is the chemical composition. Analysis of the sum of all the mineral constituents of water permits a classification based on the degree of mineralization (mineral content) (Table 1). This categorization can be extended by basing it on the content of specific constituents, which are chemical elements or compounds with proven physiological or medicinal activity (Table 1). The better known among these are

---

MS 20110570 Submitted 5/4/2011, Accepted 7/29/2011. Authors are with Dept. of Analytical Chemistry, Chemical Faculty, Gdańsk Univ. of Technology GUT, Nanutowicza Street 11/12, 80-233 Gdańsk, Poland. Direct inquiries to author Diduch (E-mail: malwina.jakubik@gmail.com).

---

iron, bromine, iodine, manganese, and carbon dioxide (van der Aa 2003).

Depending on the concentrations at which they are present, some of the constituents of water impart specific properties to the water. On this basis we can distinguish waters of varying hardness, salinity, or CO<sub>2</sub> saturation (Table 1). The temperature of the water is also a significant parameter, on the basis of which cold and thermal waters are differentiated; the latter can be further subdivided into tepid, warm, and hot waters (Table 1) (van der Aa 2003).

Natural mineral waters are classified according to geological, hydrogeological, physicochemical, and microbiological criteria. Pharmacological, physiological, and clinical criteria are also taken into account if the natural properties of the water justify this (Petraccia and others 2006). Water can be admitted for consumption only when the concentrations of its constituents do not exceed the norms specified in the table showing the various legal regulations (Table 2). When these norms are established, nutritional standards and the highest permissible levels (limiting values) in the case of harmful or potentially toxic substances have to be taken into account (Güler 2007).

## The Problems and Challenges Posed by the Analysis of Bottled Waters

Subterranean waters, the main source of mineral waters, have fairly constant physicochemical properties, and their composition is the result of the interplay of numerous hydrogeochemical processes. Anthropogenic contamination is not of the same importance for such waters as it is for surface waters. A real danger for the quality of subterranean waters, however, is their over-exploitation, which may increase the inflow of adjacent surface waters. It is also worth remembering that, in many countries, access to subterranean waters is very limited; there, the main source of bottled water is desalinated sea water (Al-Mudhaf and others 2009).

The challenge now facing analytical chemists is to develop a method for the qualitative and quantitative determinations of the wide range of analytes present in bottled waters. Determining the content of inorganic and organic compounds is difficult, mainly because of

- the low levels of individual compounds present in samples,
- the complex composition (high degree of mineralization),
- interactions between the constituents present in samples,

**Table 1—Classifications of mineral waters.**

Type of water	Parameter	Unit	Reference
<b>Criterion: mineral content</b>			
Very low mineral content	Total content of mineral salts < 50	mg/L	(van der Aa 2003)
Low mineral content	Total content of mineral salts 50–500		
Medium mineral content	Total content of mineral salts 500–1500		
High mineral content	Total content of mineral salts > 1500		
<b>Criterion: content of specific constituents</b>			
Chloride	Chlorides > 200	mg/L	(van der Aa 2003)
Bicarbonate	Bicarbonates > 600		
Sulfate	Sulfates > 200		
Sodium	Sodium > 200		
Calcium	Calcium > 150		
Magnesium	Magnesium > 50		
Iron	Iron > 1		
Bromide	Bromide > 5		
Iodide	Iodide > 1		
Manganese	Manganese > 1		
Oxalic	CO <sub>2</sub> > 250		
Fluoride	Fluoride > 1		
Sulfide	Sulfide > 1		
Arsenic	Arsenic > 0.7		
<b>Criterion: salinity</b>			
Fresh	Cl < 5	mg/L	(van der Aa 2003)
Slightly saline	Cl 5–30		
Saline	Cl 30–150		
More saline	Cl 150–300		
Very saline	Cl 300–1000		
Mineral	Cl 1000–10000		
<b>Criterion: hardness</b>			
Very soft	Ca + Mg 0–0.5	mEq/L	(van der Aa 2003)
Soft	Ca + Mg 0.5–1		
Medium hard	Ca + Mg 1–2		
Hard	Ca + Mg 2–4		
Very hard	Ca + Mg > 4		
<b>Criterion: CO<sub>2</sub> saturation</b>			
Unsaturated	No CO <sub>2</sub>	mg/L	(van der Aa 2003)
Slightly saturated	CO <sub>2</sub> < 1500		
Medium saturated	CO <sub>2</sub> 1500–4000		
Highly saturated	CO <sub>2</sub> 4000–6000		
<b>Criterion: temperature</b>			
Cold	< 20	°C	(Petraccia and others 2006)
Thermal			
Tepid	20–30		
Warm	30–40		
Hot	40		

- possible changes in composition during transport and storage as a result of reactions and the potential desorption of constituents from packaging materials, and
- the interdependence between constituents present in samples (for example, the Ca:Mg ion ratio).

**Method for determining the organic and inorganic constituents of bottled waters**

It is frequently the case that quality control of bottled water is limited to the determination of the levels of inorganic constituents such as the anions Br<sup>-</sup>, BrO<sub>3</sub><sup>-</sup>, Cl<sup>-</sup>, ClO<sub>3</sub><sup>-</sup>, ClO<sub>4</sub><sup>-</sup>, F<sup>-</sup>, I<sup>-</sup>, NO<sub>2</sub><sup>-</sup>, NO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, PO<sub>4</sub><sup>3-</sup>, HCO<sub>3</sub><sup>-</sup>; the cations Na<sup>+</sup>, K<sup>+</sup>, NH<sub>4</sub><sup>+</sup>, Mg<sup>2+</sup>, Ca<sup>2+</sup> (Azoulay and others 2001; Saleh and others 2001; Rosborg and others 2005; Morr and others 2006; Bong and

others 2009); and certain metals, Be, Cd, Cr, Cu, Hg, Fe, Mg, Mn, Ni, Se, Sr, V, Zn, Co, Hg, Pb, Th, U, Li, As, Al, Ba, Bi, Zr, Sn, Rb, Sb, Sc, Te, Tl (Al.-Saleh and Al.-Doush 1998; Saleh and others 2001; Ikem and others 2002; Costa and others 2003; Baba and others 2007; Shotyk and Krachler 2007a, 2007b; Westerhoff and others 2008; Keresztes and others 2009; Krachler and Shotyk 2009). Other elements, such as boron, are rarely determined. Table 3 provides data on the analytical techniques used for determining the inorganic constituents of bottled water.

The information available in the literature on the analytical techniques for determining the concentrations of organic compounds in bottled mineral waters is of fairly recent date, the first information on this subject having appeared in 2002. But the problem probably existed long before mineral water began to be sold in

**Table 2—Regulations and standards for water intended for human consumption.**

Parameter	Unit	ECC <sup>a</sup> (1998)	ECC <sup>a</sup> (2003)	WHO <sup>a</sup> (2008)	EPA <sup>a</sup> (2009)	IBWA <sup>a</sup> (2009)	FDA <sup>a</sup> (2010)	Polish legalization
		Drinking water (MAC) <sup>b</sup>	Bottled water (MAC) <sup>b</sup>	Drinking water (GV) <sup>c</sup>	Drinking water (MCL) <sup>d</sup>	Bottled water (SOQ) <sup>e</sup>	Bottled water (SOQ) <sup>e</sup>	Dz. U. Nr 276, poz. 2738 <sup>a</sup> (2004) Bottled water (MAC) <sup>b</sup>
<b>Disinfectants and disinfection by products</b>								
Bromate	mg/L	0.01	—	0.01	0.01	0.01	0.01	—
Chlorine	mg/L	—	—	5 <sup>f</sup>	0.1	0.1	4.0	—
Chlorite	mg/L	—	—	0.7 <sup>f</sup>	1	1	1	—
Haloacetic acids	mg/L	—	—	—	0.06	0.06	0.06	—
Total trihalogenometals	mg/L	0.1	—	1	0.08	0.01	0.08	—
<b>Inorganic chemicals</b>								
Aluminum	mg/L	0.2	—	—	—	0.2	0.2	—
Amonium	mg/L	0.5	—	—	—	—	—	2
Antimony	mg/L	0.005	0.005	0.02	0.006	0.006	0.006	0.005
Arsenic	mg/L	0.01	0.01	0.01 <sup>f</sup>	0.01	0.01	0.01	0.01
Barium	mg/L	—	—	0.7	2	1	2	1
Beryllium	mg/L	—	—	—	0.004	0.004	0.004	—
Boron	mg/L	1	1	0.5 <sup>f</sup>	—	—	—	5
Cadmium	mg/L	0.005	0.003	0.003	0.005	0.005	0.005	0.003
Chloride	mg/L	250	—	—	—	250	250	250
Chrome	μg/L	0.05	0.05	—	0.1	0.05	0.1	0.05
Copper	mg/L	2	1	2	1.3 <sup>g</sup>	1	1	1
Cyanide	mg/L	0.05	0.07	0.07	0.2	0.1	0.1	0.07
Fluoride	mg/L	1.5	5	1.5	4.0	see	see	5
Iron	mg/L	0.2	—	—	—	0.3	0.3	0.5
Lead	mg/L	0.01	0.01	0.01	0.015 <sup>g</sup>	0.005	0.005	0.01
Manganese	μg/L	0.05	0.5	0.4 <sup>f</sup>	—	0.05	0.05	0.5
Mercury	mg/L	0.001	0.001	0.006	0.002	0.001	0.002	0.001
Molybdenum	mg/L	—	—	0.07	—	—	—	—
Nickel	mg/L	0.02	0.02	0.07	—	0.1	0.1	0.02
Nitrate	mg/L	50	50	50	10 <sup>h</sup>	10	10	50
Nitrite	mg/L	0.5	0.1	0.2 <sup>f</sup>	1 <sup>h</sup>	1	1	0.1
Selenium	mg/L	0.01	0.01	0.01	0.05	0.01	0.05	0.01
Silver	mg/L	—	—	—	—	0.025	0.1	—
Sodium	mg/L	200	—	—	—	—	—	200
Sulfate	mg/L	250	—	—	—	250	250	250
Thallium	mg/L	—	—	—	0.002	0.002	0.002	—
Uranium	mg/L	—	—	0.015 <sup>f</sup>	0.03	0.03	0.03	—
Zinc	mg/L	—	—	—	—	5	5	1
<b>Organic chemicals</b>								
Acrylamide	mg/L	0.0001	—	0.0005	—	—	—	—
Benzene	mg/L	0.001	—	0.01	0.005	0.001	0.005	—
Total pesticides	μg/L	0.5	—	—	—	—	—	0.5
PAHs	μg/L	0.1	—	—	—	—	—	0.1
Phenolics	mg/L	—	—	—	—	0.001	0.001	0.002

<sup>a</sup> Sources (see References): EEC = European Economic Community; WHO = World Health Organization; EPA = US Environmental Protection Agency; IWBA = International Bottled Water Association; FDA = U.S. Food and Drug Administration; Dz. U. Nr 276, poz. 2738 (Official acts of Polish Government).

<sup>b</sup> Maximum admissible concentration.

<sup>c</sup> Guideline value.

<sup>d</sup> Maximum contaminant level.

<sup>e</sup> Standard of quality.

<sup>f</sup> Provisional guideline value.

<sup>g</sup> Action level.

<sup>h</sup> Measured as nitrogen.

plastic bottles, as evidenced by the ubiquity of organic compounds in the various compartments of the environment. The following groups of organic compounds have been determined in samples of bottled water: pesticides, volatile organic compounds, perfluorinated carbon compounds, and carbonyl compounds (Nawrocki and others 2002; Ericson and others 2008; Greulich and Alder 2008; Al-Mudhaf and others 2009; Diaz and others 2009). Table 4 gives data on the analytical procedures for determining organic compounds in bottled waters.

## Levels of Target Inorganic and Organic Constituents of Bottled Waters

### Inorganic constituents (natural and contaminants) of bottled waters

The analytical results given in the literature (Table 5) show the breadth of the range of parameters determined in bottled waters. The differences in the compositions of particular waters are very evident. This is the direct result of the geology of the region from which the water is drawn, and also of the legislation in force in a particular country. The differences in mineral content directly affect the taste and odor of the water. Bottled waters are perceived by many to taste better, have fewer impurities, and to confer higher social status on the consumer than does tap water (Saad and others 1998). Mineral water is also often used as a replacement for tap water, which is always chemically disinfected (Nawrocki and others 2002).

The main dangers to the quality of subterranean water that are sources of bottled water stem from area pollution caused by the application of agricultural chemicals, the lack or malfunction of sewage disposal systems, negligently planned landfill sites, and the insufficient number and poor efficiency of sewage treatment plants, effluent basins, sewage ponds, and poorly designed and executed

petrol stations. Line-level sources can also include leaking pipes, gas mains, and sewers (Polkowska 2003).

### Organic contaminants in bottled waters

Bottled mineral waters are a special case as far as the analysis of organic contaminants is concerned. Apart from substances derived from various compartments of the environment, like pesticides (Greulich and Alder 2008; Diaz and others 2009;) and perfluoro derivatives (Ericson and others 2008), as well as those that can form during the treatment of water (Al-Mudhaf and others 2009), the material from which the bottle or container is made can also constitute a source of contamination (Nawrocki and others 2002). Table 6 lists the levels of organic contaminants determined in bottled waters.

PET is the usual material from which bottles for mineral water are made. Studies of the possible migration of PET degradation products have shown that if bottled water is stored at elevated temperatures or exposed to sunlight, the aldehyde content in the water increases (Nawrocki and others 2002). Moreover, the size of the bottle is of greater concern. Water stored in small-capacity bottles (0.2 to 0.25 L) contains more contaminants than that in bottles of larger capacity (1.5 L). It has also been demonstrated that the bottle material degrades faster if the water is carbonated (Azoulay and others 2001; Burlingame 2003; Bong and others 2009).

Studies of the possible degradation of the polymers from which bottles are made is of major importance, because in developing countries a process known as solar disinfection is frequently used to rid the water of microorganisms. This is a simple, cheap, and effective method: the bottle is filled with water, capped, then exposed to solar radiation for 15 to 18 h (Schmid and others 2008).

**Table 3—Analytical techniques for determining inorganic constituents.**

Parameter	Type of water	Analytical technique	Validation parameters	Reference
Be, Cd, Cr, Cu, Hg, Fe, Mg, Mn, Ni, Se, Sr, V, Zn	Bottled	ICP-PED	Detection limit ( $\mu\text{g}/\text{mL}$ )	(Al-Saleh and Al Doush 1998)
Ag, Al, As, Ca, Cd, Co, Cr, Cu, Fe, Hg, Mg, Mn, Mo, Na, Pb, Th, U, Zn, Ca, K, Mg, Na	Bottled	ICP-OES	-0.000098–0.018	(Ikem and others 2002) (Rosborg and others 2005)
Sb	Bottled	ICP-MS	Detection limit ( $\mu\text{g}/\text{L}$ ) 0.004–0.028	(Westerhoff and others 2008)
Ag, Al, As, B, Ba, Be, Bi, Br, Ca, Ce, Cd, Co, Cu, Cr, Cs, Fe, Ge, Hg, I, Li, Mg, Mn, Mo, Na, Pb, Rb, Se, Sb, Sc, Sr, Te, Ti, Tl, Th, U, V, W, Zn, Zr	Bottled	ICP-MS	– Detection limit ( $\mu\text{g}/\text{L}$ ) 0.01–10 Recovery (%) 91.6–111 Detection limit ( $\mu\text{g}/\text{L}$ ) 0.001–26	(Krachler and Shoty 2009) (Saleh and others 2001) (Rosborg and others 2005)
Al, B, Ba, Bi, Ca, Cd, Co, Cr, Cu, Fe, La, Mn, Ni, Pb, Sb, Sn, Sr, Ti, U, Zn, Zr	Bottled (c, nc)	ICP-AES	–	(Baba and others 2007)
Ca, K, Mg, Na	Bottled	–	–	(Bong and others 2009)
Sb	Bottled (c, nc)	ICP-SF-MS	Detection limit ( $\text{pg}/\text{mL}$ ) 0.7	(Keresztes and others 2009)
$\text{NO}_3\text{-N}$	Bottled	FIA	Detection limit ( $\mu\text{g}/\text{L}$ ) 60	(Rosborg and others 2005)
F, Cl, $\text{SO}_4\text{-S}$	Bottled	IC-CD	Detection limit ( $\mu\text{g}/\text{L}$ ) 100–190	(Rosborg and others 2005)
Br, $\text{BrO}_3^-$ , Cl, $\text{ClO}_3^-$ , F, I, $\text{NO}_2^-$ , $\text{NO}_3^-$ , $\text{SO}_4^{2-}$ , $\text{PO}_4^{3-}$	Bottled	–	–	(Saleh and others 2001, Liu and Mou 2004)
Cl, $\text{NO}_3^-$ , $\text{SO}_4^{2-}$ , $\text{HCO}_3^-$	Bottled	–	–	(Bong and others 2009)
Ba, Ca, Cr, Cu, Ge, K, Mn, Ni, Pb, Rb, Sr, Ti, Zn	Bottled (c, nc)	STR-XRF	Detection limit ( $\mu\text{g}/\text{L}$ ) 0.02–22.2	(Costa and others 2003)
As, Ca, Cd, Cu, K, Mg, Na, P, Se, Zn	Bottled	MIP-MS	–	(Chiba and others 2006)
$\text{ClO}_4^-$	Bottled	ESI-MS-MS	–	(Shi and others 2007)

c = carbonated, nc = noncarbonated.

Table 4—Analytical techniques for determining organic constituents.

Parameter	Type of water	Sample preparation	Analytical technique	Reference
<b>Pesticides</b>				
$\alpha$ -HCH	Bottled 1.5–19L	A 500 mL aliquot of each bottled water sample was transferred to a separating funnel, then extracted by shaking with 75 mL of ether–hexane (25%, v/v). Separately another 500 mL aliquot was extracted with 75 mL of hexane and the two extracts combined so that 1 L of sample was extracted in total. The organic phase was passed through anhydrous sodium sulfate to remove remnants of water then the samples evaporated in a rotary evaporator to 5 mL.	GC-ECD	(Diaz and others 2009)
$\beta$ -HCH				
$\beta$ -HCH				
$\delta$ -HCH				
Aldrin				
DDD				
DDE				
DDT				
Dieldrin				
Endosulfan I				
Endosulfan II				
Endosulfan sulfate				
Endrin				
Endrin aldehyde				
<b>Volatile organic compounds</b>				
1,2,4-Trimethylbenzene	Bottled	In this method, VOCs and surrogates with low water solubility are extracted (purged) from the sample matrix by bubbling helium gas through the aqueous sample. Purged sample components are trapped in a tube containing suitable sorbent materials. When purging is complete, the sorbent tube is heated and backflushed with helium to desorb the trapped sample components into a capillary GC column interfaced to the MS. Bottled water was directly analyzed without the addition of sodium thiosulfate. The US Environmental Protection Agency (EPA) method 52.2 with some modifications was employed for purge and trap extraction of THMs and analysis by gas chromatography/mass spectrometry.	GC-MS	(Leivadara and others 2008, Al-Mudhaf and others 2009, Ahmad and Bajahlan 2009, Ikem 2002, Saleh and others 2001)
1,2-Dichloropropane				
1,3,5-Trimethylbenzene				
1,3-Dichlorobenzene				
Bromodichloromethane				
Bromoform				
Chloroform				
Dibromochloromethane				
Dibromomethane				
Ethylbenzene				
<i>iso</i> -Propylbenzene				
Xylene				
Naphthalene				
Styrene				
Toluene				
Trichloroethene				
Chloral-hydrate				
Trichloropropanone				
Dichloroacetonitrile				
<b>Haloacetic acid</b>				
Formic acid	Bottled (purified, mineral, natural)	Samples were filtered with 0.45 $\mu$ m filters. One hundred-milliliter polytetrafluoroethylene (PTFE) beakers were used for sample concentration. The beakers were cleaned a 150 W AS3120A sonicator.	IC-ED	(Liu and Mou 2003)
Dichloroacetic acid				
Ethanedioic acid				
<b>Antioxidant</b>				
Butylated hydroxytoluene	Bottled 0.5–2L	Solid-phase micro extraction (SPME) was implemented and applied for the extraction of BHT 2.2 from water samples and further determination by capillary gas chromatography–mass spectrometry. Used an SPME manual holder and fiber assembly with a 100 mm polydimethylsiloxane film, and an amber screw-top vial with white PTFE–silicone septa. The fiber was exposed to 15 mL aliquots (maximum capacity). Extractions were performed at room temperature (20 to 25 °C). The expon time was 30 min.	GC-MS	(Tombesi and Freije 2002)
4-Nonylphenol bisphenol A triclosan	Bottled (mineral, pure)	Before extraction, the pH value of each water sample was adjusted to 3 using 4 M H <sub>2</sub> SO <sub>4</sub> and 50 mL of HPLC-grade methanol was added into the water to increase extraction efficiency. And 100 $\mu$ L each of 1 mg/L of 4-n-NP, BPA-d16 and 13C-TCS were spiked into each sample as internal standards. The cartridges were conditioned by 10 mL of methanol and 10 mL of Milli-Q water. Then water samples passed through the SPE cartridges at a flow rate of 10 mL/min. After loading of the samples, the cartridges were dried under vacuum for 2 h. The analytes were eluted from the cartridges using 8 mL ethyl acetate. The eluates were concentrated to dryness under a gentle stream of nitrogen, and then redissolved in methanol to a final volume of 1 mL. Each final extract was filtered through a 0.45 $\mu$ m membrane filter into a 2 mL amber glass vial and kept at –18 °C until analysis. First, 100 $\mu$ L of the final extract in methanol was transferred to the test	GC-MS-NCI	(Li and others 2010)

(Continued)



Table 4—Continued

Parameter	Type of water	Sample preparation	Analytical technique	Reference
		<p>tube and the solvent was dried under a gentle nitrogen stream. Secondly, 2 mL of 1 M NaHCO<sub>3</sub> and 1 mL of 1 M NaOH were added. After shaking for 30 s, 2 mL of n-hexane, 50 μL of 10% pyridine in toluene and 50 μL of 2% PFBOCl in toluene were added. The tube was tightly capped and handshaken violently for 1 min. After the organic phase and aqueous phase were separated thoroughly, the organic phase was transferred to a 5 mL glass centrifuge tube using a glass pipette. Third, 2 mL of n-hexane was added to the 10 mL tube for a second extraction. The tube was handshaken for 1 min, and the other procedures were the same as in the second step. After separated, the supernatant was transferred to the aforementioned 5 mL glass centrifugal tube. Then the combined n-hexane mixture was dried under a gentle nitrogen stream. Finally, the extract was redissolved in 100 μL of n-hexane, and then transferred to a 2 mL amber glass vial with a 250 μL flat-bottomed insert, which was ready for GC-NCI-MS analysis.</p>		
<b>Perfluorochemicals</b>				
PFBuS	Bottled	Samples were filtered with glass microfiber filters.	HPLC-MS	(Ericsson and others 2008)
PFDA		Samples were concentrated using solid-phase extraction. Briefly, 500 mL of water were used for extraction after adjusting the pH to 4 using an HCl solution. Extraction standards, 13C4-PFOS and 13C4-PFOA, and 10 mL of methanol (MeOH) were added. After 10 min, water samples were loaded onto Waters Oasis <sup>®</sup> WAX single use cartridges (6 cm <sup>3</sup> /150 mg) previously conditioned with 4 mL MeOH and 4 mL water. Vacuum was used to speed up the concentrations of water samples. After drying, SPE cartridges were eluted with 4 mL acetate buffer solution (discarded) and 2 mL 2% NH <sub>4</sub> in MeOH (target fraction). This fraction was filtered (2 μm nylon filter) and evaporated under nitrogen. The final volume was set to 500 μL including 13C5-labeled PFNA added as performance standard and 300 μL of 2 mM sodium acetate in water.		
PFDoDA				
PFDS				
PFHpA				
PFHxA				
PFHxS				
PFNA				
PFOA				
PFOS				
PFOSA				
PFTDA				
PFUnDA				
THPFOS				
Formaldehyde	0.5–1.5 L; c, nc	20 mL of water samples were collected in glass vials with glass caps. One milliliter of 1 mg/mL aqueous PFBOA solution was added to the sample and kept at room temperature for 1 h, then 2 drops of concentrated sulfuric acid were added to complete the derivatization reaction. The extract was then purified with 3 mL of 0.2 N sulfuric acid solution. The hexane layer was separated and transferred to vials containing approximately 50 mg of sodium sulfate to dry the extract	GC-ECD	(Nawrocki and others 2002)
Acetaldehyde				
Acetone				

## Summary

Bottled water is a product that is purchased by annually increasing numbers of people of all age groups. The quality control of mineral waters tends to concentrate on the determination of anion and cation levels, since it is these that govern the taste, odor, and possible nutraceutical properties of the water. The diversity of mineral waters causes problems in drawing up a uniform classification system that would make it easier for the consumer to choose a water suitable for his/her individual needs. In addition, the broad spectrum of inorganic constituents in mineral waters precludes the application of any one particular analytical technique. Ion chromatography remains the most popular method of determining the levels of ions in such waters.

The constantly rising sales of mineral waters bring with them ever-increasing exploitation of their sources. The consequences of this include deterioration in the quality of subterranean wa-

ters, for example, as a result of the inflow of adjacent ground waters, which are often exposed to anthropogenic contamination. The implication is that not only the mineral content but also the levels of possible organic contaminants must be subjected to constant quality control measures. If bottled water is not stored under the right conditions, that is to say, if it is exposed to high temperatures and/or sunlight, it can become contaminated by the degradation products of the material from which the bottle was made. This is a fairly new problem. Techniques such as GC-ECD, GC-MS, and HPLC-MS are used to determine organic contaminants in samples of bottled water. Emptied bottles are a serious danger to the environment. They are constantly increasing in number, yet no system for their reuse has met with approval. It is still the case that only a small fraction of them is recycled, which makes them one of the most troublesome items of refuse.

Table 5—Levels of inorganic constituents in bottled waters (literature information).

Country	Brand	Type of water	Parameter	Range	Unit	References	
<b>Europe</b>							
England	Abbey Well Aqua-Pura Brecon Carreg Buxton Chiltern Highland Spring Strathmore	lm	Ca	39–114	mg/L	(Azoulay and others 2001)	
			Mg	1–36			
			Na	6–46			
Austria	Montes	c	Ca	8157	$\mu\text{g/L}$	(Bong and others 2009)	
			Cl	1059			
			HCO <sub>3</sub> <sup>-</sup>	28331			
			K	443			
			Mg	4056			
			Na	4309			
	Romerquelle	mm		Ca	146	mg/L	(Azoulay and others 2001)
				Mg	65		
				Na	13		
				Ca	57		
				Mg	37		
				Na	5		
Belgium	Bru	lm	Ca	23	mg/L	(Azoulay and others 2001, Morr and others 2006)	
			Mg	23			
			Na	10			
	Chaudfontaine	m		Ca	65		
				Mg	18		
				Na	44		
	Duke Leberg	s		Ca	10–112		
				Mg	6–47		
				Na	5–10		
	Valvert	lm		Ca	67.7–68		
				Mg	2		
				Na	1.9–2		
Finland	Vichi original	mm	Ca	100	mg/L	(Azoulay and others 2001)	
			Mg	110			
			Na	220			
	Vichy Nouvelle	lm		Ca	70		
				Mg	110		
				Na	1		
France	Aix les Banes	m	Ca	72	mg/L	(Saleh and others 2001, Bong and others 2009, Azoulay and others 2001, Morr and others 2006)	
			Mg	38			
			Na	14			
	Badoit	mm		Ca	200–467		
				Mg	84–100		
				Na	7–160		
	Contrex	m		Ca	157		
				Mg	21		
				Na	14		
	Evian	s. plastic		Al	0.006	$\mu\text{g/L}$	
				Ca	0.05	mg/L	
				Cd	< 0.2	$\mu\text{g/L}$	
				Cl	18	mg/L	
				Co	1	$\mu\text{g/L}$	
				Cr	< 0.2		
				Cu	< 0.2		
				Fe	1.09		
				Hg	51		
				K	27.3	mg/L	
				Mg	1–24		
				Mn	5	$\mu\text{g/L}$	
Na				5–6.38	mg/L		
SO <sub>4</sub> <sup>2-</sup>				2.29			
U				4	$\mu\text{g/L}$		
Zn	8						
Perrier	lm. nc		Ca	78	mg/L		
			Ca	4538–147000	$\mu\text{g/L}$		
			Cl	474			

(Continued)



Table 5—Continued

Country	Brand	Type of water	Parameter	Range	Unit	References
			HCO <sub>3</sub> <sup>-</sup>	1171		
			K	27.4		
			Mg	254–4000		
			Na	535–14000		
			NO <sub>3</sub> <sup>-</sup>	103		
			SO <sub>4</sub> <sup>2-</sup>	424		
	Prince Noir	m	Ca	528	mg/L	
			Mg	78		
			Na	9		
	SaintYorre	hm	Ca	100–176		
	Vichy Celestins		Mg	9–160		
			Na	900–1200		
	Vittel Bonne Sources	lm	Ca	91		
			Mg	20		
			Na	7		
	Vittel Grande Source	mm	Ca	202–575		
	Vittel Hepar		Mg	36–118		
			Na	3–13		
	Volvic	lm	Ca	299–10000	μg/L	
			Cl	438–442		
			HCO <sub>3</sub> <sup>-</sup>	1323–1352		
			K	137–145		
			Mg	344–6100		
			Na	502–9400		
			NO <sub>3</sub> <sup>-</sup>	119–120		
			SO <sub>4</sub> <sup>2-</sup>	88.5–89.6		
Spain	Font Vella	lm	Ca	26–35	mg/L	(Azoulay and others 2001)
	Fonter		Mg	5–7		
			Na	11–12		
	Salus Vidago	mm	Ca	78		
			Mg	10		
			Na	660		
	San Narciso	hm	Ca	33–53		
	Vichy Catalan		Mg	8–9		
			Na	1120–1133		
	Viladru	lm	Ca	16		
			Mg	2		
			Na	9		
Ireland	Ballygowan	lm	Ca	37–114	mg/L	(Azoulay and others 2001)
	Glenpatrick Spring		Mg	15–23		
	Tipperary		Na	12–25		
Iceland	Thorspring	lm	Ca	6	mg/L	(Azoulay and others 2001)
			Mg	1		
			Na	8		
Germany	Apollinaris	mm, c	Ca	2.7–89	mg/L	(Azoulay and others 2001,
			Cl	3660	μg/L	Morr and others 2006)
			HCO <sub>3</sub> <sup>-</sup>	31778		
			K	893		
			Mg	5.9–104	mg/L	
			Na	23–425		
			NO <sub>3</sub> <sup>-</sup>	78.1	μg/L	
			SO <sub>4</sub> <sup>2-</sup>	1023		
	Azur	m	Ca	177	mg/L	
			Mg	29.9		
			Na	176		
	Fachingen	mm	Ca	113		
			Mg	62		
			Na	500		
	Gerolsteiner	c	Ca	2610–2991	μg/L	
			Cl	127–135		
			HCO <sub>3</sub> <sup>-</sup>	7262–7353		
			K	10.5–11.6		
			Mg	1319–1447		
			Na	144–161		
			NO <sub>3</sub> <sup>-</sup>	171–182		
			SO <sub>4</sub> <sup>2-</sup>	167–184		
	Gerolsteiner Sprudel	mm	Ca	176–364	mg/L	
	Hassia Sprudel		Mg	36–113		
			Na	119–232		

(Continued)



Table 5—Continued

Country	Brand	Type of water	Parameter	Range	Unit	References				
	Hella	lm	Ca	51						
			Mg	4						
			Na	8						
	Kaiser Friedrich	hm	Ca	5						
			Mg	4						
			Na	1419						
	Peterstaler Rippoldsauer	mm	Ca	216–256						
			Mg	37–128						
			Na	40–215						
	Robacher St. Michaelis	lm	Ca	43						
			Mg	4						
			Na	21						
Uberkinger	hm	Ca	26							
		Mg	17							
		Na	1180							
Poland	Krystynka	hm	Ca	176	mg/l	(Azoulay and others 2001)				
			Mg	60						
			Na	900						
	Nałęczowianka	mm	Ca	119						
			Mg	21						
			Na	24						
Portugal	Pedras Saldagas	mm	Ca	132	mg/L	(Azoulay and others 2001)				
			Mg	9						
			Na	550						
Slovenia	Radenska	mm	Ca	217	mg/L	(Azoulay and others 2001)				
			Mg	97						
			Na	470						
Switzerland	Aproz	mm	Ca	454	mg/L	(Azoulay and others 2001, Bong and others 2009)				
			Mg	67						
			Na	8						
	Cristalp	lm	Ca	115	mg/L					
			Mg	40						
			Na	20						
	Heidiland	c	Ca	2941	$\mu\text{g/L}$					
			Cl	42.3						
			HCO <sub>3</sub> <sup>-</sup>	1405						
			K	14.2						
			Mg	1642						
			Na	189						
			NO <sub>3</sub> <sup>-</sup>	33.4						
			SO <sub>4</sub> <sup>2-</sup>	2682						
			Henniez	lm			Ca	111	mg/L	
							Mg	19		
							Na	9		
			Passugger Valser	mm			Ca	286–436		
Mg	24–54									
Na	11–46									
Italy	Aqua di Nepi Aqua Fabia	lm	Ca	72–124	mg/L	(Bong and others 2009, Azoulay and others 2001, Morr and others 2006)				
			Mg	5–26						
			Na	15–32						
	Aqua Panna	lm, nc	Ca	912–15000						
			Cl	241						
			HCO <sub>3</sub> <sup>-</sup>	1975						
			K	22.1						
			Mg	302–5000						
			Na	355–3000						
	Boario Claudia	lm	Ca	60–124						
			Mg	2–41						
			Na	6–56						
Crodo Lisiel Crodo Valle d'Oro Ferrarelle	mm	Ca	408–510							
		Mg	23–51							
		Na	2–50							
Fiuggi Levissima	lm	Ca	15–18							
		Mg	1–5							
		Na	1–6							
Maxim's	s	Ca	20.2							
		Mg	1.6							
		Na	3.9							

(Continued)



Table 5—Continued

Country	Brand	Type of water	Parameter	Range	Unit	References
Asia Korea	Pracastello	mm	Ca	164	$\mu\text{g/L}$	(Bong and others 2009)
			Mg	46		
	Na	28				
	Ca	4701–208000				
	S. Pellegrino	mm, c	Cl	1810		
			$\text{HCO}_3^-$	3495		
			K	74.5		
			Mg	2361–55900		
			Na	1596–43600		
			$\text{NO}_3^-$	50.6		
			Ca	43		
	San Benedetto	lm	Mg	25		
			Na	8		
	San Bernardo	lm, c	Ca	1334–12000		
			Cl	91.3		
			$\text{HCO}_3^-$	4815		
			K	26.6		
			Mg	1000–1313		
			Na	325–1000		
			$\text{NO}_3^-$	139		
			$\text{SO}_4^{2-}$	49.6		
			Ca	204–414		
			San Pellegrino Sanfaustino	m		
	Na	17–47				
	Sangemini	mm	Ca	322		
			Mg	19		
	Solé	nc	Na	21		
			Ca	10.8		
			Cl	298		
			$\text{HCO}_3^-$	1740		
			K	2359		
			Mg	8.47		
			Na	77.9		
			$\text{NO}_3^-$	16.7		
	Vera	lm	$\text{SO}_4^{2-}$	5.85		
			Ca	34		
			Mg	12		
			Na	2		
			Ca	386		
	Bongpyong	nc	Cl	174		
			$\text{HCO}_3^-$	1011		
			K	15.2		
			Mg	124		
			Na	291		
			$\text{NO}_3^-$	120		
			$\text{SO}_4^{2-}$	38.5		
			Ca	597		
Cl			480			
$\text{HCO}_3^-$			1488			
Chojung	c	K	35.9			
		Mg	220			
		Na	938			
		$\text{NO}_3^-$	225			
		$\text{SO}_4^{2-}$	127			
		Ca	783			
		Cl	150			
		$\text{HCO}_3^-$	1318			
		K	30.1			
		Mg	156			
Dongwon	nc	Na	274			
		$\text{NO}_3^-$	47.2			
		$\text{SO}_4^{2-}$	358			
		Ca	194–262			
		Cl	170–184			
		$\text{HCO}_3^-$	983–1096			
		K	16.1–18.3			
		Mg	29.4–39.3			
Elumgol	c	Na	1006–1017			
		$\text{NO}_3^-$	90.2–100			
		$\text{SO}_4^{2-}$	128–137			

(Continued)

Table 5—Continued

Country	Brand	Type of water	Parameter	Range	Unit	References
	Icis	nc	Ca	6.7–586	μg/L	
	Keumgangsoob		Cl	76–393		
	Odaesan		HCO <sub>3</sub> <sup>-</sup>	41–2705		
	Power O2		K	7–2359		
	Samdasoo		Mg	7.6–553		
	Sammool		Na	64.5–929		
	Seoksu		NO <sub>3</sub> <sup>-</sup>	16.7–131		
	Siana		SO <sub>4</sub> <sup>2-</sup>	5.8–304		
	Soo					
	Soonsoo					
	T <sup>^</sup> ynant					
	Tynant	c	Ca	601	μg/L	
	Tau		Cl	390		
			HCO <sub>3</sub> <sup>-</sup>	2033		
			K	21.7		
			Mg	551		
			Na	948		
			SO <sub>4</sub> <sup>2-</sup>	75.2		
	Waterline	nc	Ca	573–617	μg/L	
	Yaksan		Cl	105–115		
			HCO <sub>3</sub> <sup>-</sup>	1570–1661		
			K	23.2–24.3		
			Mg	200–211		
			Na	187–228		
			NO <sub>3</sub> <sup>-</sup>	66.6–76.2		
			SO <sub>4</sub> <sup>2-</sup>	108–129		
<b>North America</b>						
Fiji	Fiji	s	Ca	17	mg/L	(Morr and others 2006)
			Mg	13		
Canada	Aberfoyle	s. plastic	Al	4	μg/L	(Azoulay and others 2001, Bong and others 2009, Ikem and others 2002)
			Ca	0.05	mg/L	
			Cd	0.2	μg/L	
			Cl	49.77	mg/L	
			Co	1	μg/L	
			Cr	<0.2		
			Cu	1		
			Fe	0.001		
			Hg	14		
			K	1.82	mg/L	
			Mg	24.5		
			Mn	< 0.1	μg/L	
			Mo	< 0.7		
			Na	23	mg/L	
			SO <sub>4</sub> <sup>2-</sup>	79.69		
			Zn	27	μg/L	
	Canada Geese	m	Ca	282	mg/L	
			Mg	10		
			Na	36		
	Canadian Spring	s	Ca	11–20		
	Clairval		Mg	3–7		
			Na	2–13		
	Dannon	s. plastic	Ag	0.3 ± 0.6	μg/L	
			Al	2.7 ± 2.5		
			Ca	21.95 ± 22.45	mg/L	
			Cl	48.76 ± 35.27		
			Co	1.7 ± 1.5	μg/L	
			Cr	0.3 ± 0.5		
			Cu	0.7 ± 0.6		
			Fe	0.001 ± 0.001		
			Hg	12 ± 16.5		
			K	1.09 ± 0.91	mg/L	
			Mg	7.10 ± 2.84		
			Na	23.52 ± 18.23		
			Pb	0.3 ± 0.5	μg/L	
			SO <sub>4</sub> <sup>2-</sup>	20.40 ± 7.24	mg/L	
			U	0.7 ± 1.1	μg/L	
			Zn	8 ± 8.7		
	Montclair	m	Ca	3–8	mg/L	
	Montellier		Mg	3–12		
			Na	340–475		

(Continued)



Table 5—Continued

Country	Brand	Type of water	Parameter	Range	Unit	References		
USA	Naya	s	Ca	38				
			Mg	20				
			Na	6				
	Whistler	nc	Ca	311	$\mu\text{g/L}$			
			Cl	166				
			HCO <sub>3</sub> <sup>-</sup>	556				
			K	14.7				
			Mg	53.8				
			Na	109				
			NO <sub>3</sub> <sup>-</sup>	13.6				
	A Sante	m	Ca	4	$\text{mg/L}$	(Bong and others 2009, Azoulay and others 2001, Morr and others 2006, Ikem and others 2002)		
			Mg	1				
			Na	160				
			Adobe Springs	s	Ca		1–3	
					Mg		1–96	
					Na		4–5	
			Aquafina	p. plastic	Ag		1.1 ± 1.9	$\mu\text{g/L}$
					Al		1.3 ± 2.9	
					As		11.9 ± 9.1	
					Ca		0.06 ± 0.04	$\text{mg/L}$
					Cd		1 ± 1.9	$\mu\text{g/L}$
					Cl		3.9 ± 1.116	$\text{mg/L}$
					Co		2 ± 1.5	$\mu\text{g/L}$
					Cr		< 0.2	
					Cu		0.6 ± 0.8	
					Fe		0.1 ± 0.4	
					Hg		3 ± 5.1	
					K		0.05 ± 0.05	$\text{mg/L}$
					Mg		0.02 ± 0.03	
					Mo		2.3 ± 4.7	$\mu\text{g/L}$
					Na		4.28 ± 8.62	$\text{mg/L}$
					Pb		0.3 ± 0.7	$\mu\text{g/L}$
					SO <sub>4</sub> <sup>2-</sup>		0.24 ± 0.21	$\text{mg/L}$
			Th	2.3 ± 2.9	$\mu\text{g/L}$			
			U	0.7 ± 0.8				
			Zn	0.9 ± 0.7				
			Arrowhead	s	Ca		20–36	$\text{mg/L}$
	Mg	1–5						
	Na	2–12						
	Calistoga	m	Ca	7	$\text{mg/L}$			
			Mg	1				
	Canterbury	s. plastic	Na	150				
Ca			0.05	$\text{mg/L}$				
Cd			< 0.2	$\mu\text{g/L}$				
Cl			5.7	$\text{mg/L}$				
Co			< 0.4	$\mu\text{g/L}$				
Cr			< 0.2					
Cu			1					
Fe			0.001					
Hg			0.01					
K			1.79	$\text{mg/L}$				
Mg			16					
Mn			1	$\mu\text{g/L}$				
Mo			1					
Na			1.61	$\text{mg/L}$				
SO <sub>4</sub> <sup>2-</sup>			5.84					
Carolina mountain	s	Ca	5–6	$\text{mg/L}$				
		Mg	2					
Cobb mountain	s	Na	4–5					
		Ag	1–57	$\mu\text{g/L}$				
Crystal geysers Crystal springs	s. plastic	Al	0.2–3					
		As	12					
		Ca	4–26.7	$\text{mg/L}$				
		Cd	2–3	$\mu\text{g/L}$				
		Cl	6.8–49.77	$\text{mg/L}$				
		Co	0.8–1	$\mu\text{g/L}$				
		Cr	< 0.2					
		Cu	< 0.2					
		Fe	0.001–0.8					
		Hg	3–14					

(Continued)

Table 5—Continued

Country	Brand	Type of water	Parameter	Range	Unit	References
			K	0.5–1.13	mg/L	
			Mg	3.75–24.5		
			Mn	0.1–5.5	μg/L	
			Mo	0.7–8		
			Na	1.2–160	mg/L	
			Pb	0.5	μg/L	
			SO <sub>4</sub> <sup>2-</sup>	2.58–79.69	mg/L	
			Zn	27	μg/L	
	Dasani	p. plastic	Ag	0.2 ± 0.4	μg/L	(Bong and others 2009, Azoulay and others 2001, Morr and others 2006; Ikem and others 2002)
			Al	2.6 ± 4.2		
			As	6.5 ± 6.3		
			Ca	0.08–10	mg/L	
			Cd	0.7 ± 1.6	μg/L	
			Cl	8.38 ± 0.68	mg/L	
			Co	1.5 ± 1.4	μg/L	
			Cr	0.4 ± 0.9		
			Cu	0.5 ± 0.6		
			Fe	0.4 ± 0.6		
			Hg	20 ± 29.8		
			K	12.89	mg/L	
			Mg	3.10 ± 0.77		
			Mn	2 ± 7	μg/L	
			Mo	2.7 ± 3.5		
			Na	12.89 ± 31.21	mg/L	
			Pb	0.3 ± 0.5	μg/L	
			SO <sub>4</sub> <sup>2-</sup>	14.29 ± 0.99	mg/L	
			Th	3.0 ± 6.5	μg/L	
			U	2.5 ± 6.5		
			Zn	3.8 ± 10.7		
	Deep Rock	s	Ca	0.5–26.5	mg/L	
	Deer Park		Mg	1–2.6		
			Na	1–60		
	Fountainhead	s. plastic	Ag	67.8 ± 161.3	μg/L	
			Al	4.7 ± 5.6		
			As	9.7 ± 11.4		
			Ca	3.1 ± 4.74	mg/L	
			Cd	1.3 ± 2.2	μg/L	
			Cl	4.7 ± 0.92	mg/L	
			Co	1 ± 0.8	μg/L	
			Cr	< 0.2		
			Cu	0.5 ± 0.8		
			Fe	0.001 ± 0.0006		
			Hg	24.7 ± 28		
			K	1.3 ± 0.19	mg/L	
			Mg	0.34 ± 0.04		
			Mo	2.8 ± 3.1	μg/L	
			Na	5.33 ± 0.45	mg/L	
			Pb	0.2 ± 0.4	μg/L	
			SO <sub>4</sub> <sup>2-</sup>	14.56 ± 1.53	mg/L	
			Th	2.2 ± 3.0	μg/L	
			U	2.3 ± 2.7		
			Zn	2.2 ± 1.0		
	Georgia Mountain Water	s	Ca	2	mg/L	(Bong and others 2009, Azoulay and others 2001, Morr and others 2006, Ikem and others 2002)
	Goldemb	s. plastic	Ag	0.12	μg/L	
			As	4		
			Ca	0.05	mg/L	
			Cd	5	μg/L	
			Cl	6.13	mg/L	
			Cr	< 0.2	μg/L	
			Cu	< 0.2		
			Fe	0.001		
			Hg	75		
			K	0.258	mg/L	
			Mg	3.2		
			Mn	1	μg/L	
			Mo	2		
			Na	2.06	mg/L	
			SO <sub>4</sub> <sup>2-</sup>	12.94		
			Th	2	μg/L	
			U	1		
			Zn	3		

(Continued)

Table 5—Continued

Country	Brand	Type of water	Parameter	Range	Unit	References	
Great Bear		s	Ca	1–1.3	mg/L	(Bong and others 2009, Azoulay and others 2001, Morr and others 2006, Ikem and others 2002)	
			Mg	1			
Hawaiian	s. plastic		Na	1.7–3			
			Ag	2			μg/L
			Ca	0.04			mg/L
			Cd	< 0.2			μg/L
			Cl	7.17			mg/L
			Cr	< 0.2			μg/L
			Cu	1			
			Fe	0.009			
			K	2.35			mg/L
			Mg	3.47			
			Mn	1			μg/L
			Mo	2			
			Na	5.98			mg/L
SO <sub>4</sub> <sup>2-</sup>	5.63						
Th	5	μg/L					
U	1						
Zn	15						
Hawaiian Springs La Croix	s		Ca	6–37	mg/L		
			Mg	3–22			
Lithia Springs	m		Na	4–6	mg/L		
			Ca	120			
Melwood	s. plastic		Mg	7			
			Na	680			
Melwood	s. plastic		Ag	3 ± 28	μg/L		
			Al	6.4 ± 9.2			
			As	2 ± 2.8			
			Ca	1.53 ± 2.1		mg/L	
			Cl	7.17			
			Co	1 ± 1.4		μg/L	
			Cr	<0.2			
			Cu	1.5 ± 0.7			
			Fe	0.001			
			K	10.2 ± 8.77		mg/L	
			Mg	1.06 ± 0.92			
			Mn	0.5 ± 0.7		μg/L	
			Mo	3 ± 4.2			
			Na	5.98		mg/L	
			SO <sub>4</sub> <sup>2-</sup>	5.63			
			Th	5		μg/L	
			U	1			
Zn	15						
Mendocino	m		Ca	310	mg/L		
			Mg	130			
			Na	240			
Mount Olympus Mountain Valley	s		Ca	8–68	mg/L		
			Mg	2–8			
			Na	3			
Mountainvalley Oasis	s. plastic		Ca	0.05	mg/L		
			Cd	< 0.2		μg/L	
			Cl	10–23		mg/L	
			Cr	0.2		μg/L	
			Cu	0.5–2			
			Fe	0.003			
			K	0.58–1.22		mg/L	
			Mg	4.4–8			
			Mn	1		μg/L	
			Mo	2–10			
			Na	3–128		mg/L	
			SO <sub>4</sub> <sup>2-</sup>	8–16			
			Th	2–11		μg/L	
U	18						
Zn	6–11						
Ozarka	s		Ca	18	mg/L		
			Mg	1			
			Na	5			
PleasantSpring	s. plastic		Ag	1	μg/L		
			Ca	0.05		mg/L	
			Cd	1		μg/L	
			Cl	16		mg/L	

(Continued)

Table 5—Continued

Country	Brand	Type of water	Parameter	Range	Unit	References
			Cr	< 0.2	µg/L	
			Cu	1		
			Fe	0.001		
			Hg	1		
			K	52.8	mg/L	
			Mg	1.27		
			Mn	5	µg/L	
			Mo	1		
			Na	1.82	mg/L	
			SO <sub>4</sub> <sup>2-</sup>	1.59		
			Th	3	µg/L	
	Poland Spring	s	Ca	4.1	mg/L	(Bong and others 2009, Azoulay and others 2001, Morr and others 2006, Ikem and others 2002)
			Mg	0.2–1		
			Na	1.5–3		
	Prestige	s. plastic	Al	1 ± 1.4	µg/L	
			Ca	12.82 ± 18.07	mg/L	
			Cd	2.5 ± 3.5	µg/L	
			Co	0.5 ± 0.7		
			Cu	< 0.2		
			Fe	0.002 ± 0.001		
			K	0.49 ± 0.08	mg/L	
			Mg	8.166 ± 1.15		
			Mo	12.4 ± 15.1	µg/L	
			Na	6.17 ± 0.28	mg/L	
			SO <sub>4</sub> <sup>2-</sup>	9.42 ± 0.33		
			U	1 ± 1.4	µg/L	
			Zn	3.5 ± 0.7		
	Pure Spring Water	s	Ca	49	mg/L	
			Mg	4		
	Sams	p. plastic	Ag	1	µg/L	
			As	0.005		
			Ca	0.04	mg/L	
			Cd	5	µg/L	
			Cl	5.55	mg/L	
			Cr	< 0.2	µg/L	
			Cu	< 0.2		
			Fe	0.002		
			Hg	79		
			K	0.13	mg/L	
			Mg	0.09		
			Mn	0.002	µg/L	
			Mo	1		
			Na	2.64	mg/L	
			Pb	3	µg/L	
			SO <sub>4</sub> <sup>2-</sup>	2.64	mg/L	
			Th	4	µg/L	
			U	2		
			Zn	< 0.1		
	Silverspring	s. plastic	Ag	0.5–8.3	µg/L	
	Southernhome		Al	0.3		
			Ca	0.04	mg/L	
			Cd	2.8–3	µg/L	
			Cl	14.6–26.05	mg/L	
			Co	0.5–0.7	µg/L	
			Fe	0.002–1.3		
			Hg	6–12.7		
			K	0.53–0.66	mg/L	
			Mg	6.3–8.72		
			Mo	0.5–20.6	µg/L	
			Na	2.17–6.44	mg/L	
			SO <sub>4</sub> <sup>2-</sup>	9.42–10.24		
			Th	0.7–2.3	µg/L	
			U	1.3–5.3		
			Zn	3–4		
	Sparkletts	s	Ca	5	mg/L	
			Mg	5		
			Na	15		
	Springtime	s. plastic	Ag	0.5	µg/L	
	Sweetwater		Al	0.3		
			As	1		
			Ca	0.05–5.7	mg/L	
			Cl	6.7–17		

(Continued)

Table 5—Continued

Country	Brand	Type of water	Parameter	Range	Unit	References
			Co	1–2.5	μg/L	
			Cu	0.5–0.7		
			Fe	0.5–0.7		
			Hg	7.7		
			K	0.57–3	mg/L	
			Mg	1.6–2.2		
			Mo	1.7	μg/L	
			Na	8–143	mg/L	
			SO <sub>4</sub> <sup>2-</sup>	1.7–8.9		
			Th	7	μg/L	
			U	2.5–4.7		
			Zn	2–3		
	Talawanda Spring	s	Ca	2–76	mg/L	
	Talking Rain		Mg	2–17		
	Utopia		Na	3–8		
	Vichy Springs	m	Ca	157	mg/L	
			Mg	48		
			Na	1095		
	Zephyrhills	s. plastic	Ag	11.4 ± 25.5	μg/L	(Bong and others 2009,
			Al	0.6 ± 0.9		Azoulay and others 2001;
			As	0.8 ± 1.8		Morr and others 2006;
			Ca	10.52 - 58	mg/L	Ikem and others 2002)
			Cd	2 ± 2.3	μg/L	
			Cl	15.13 ± 1.24	mg/L	
			Co	0.8 ± 1.0	μg/L	
			Cr	0.2 ± 0.4		
			Cu	0.6 ± 0.9		
			Fe	0.6 ± 0.5		
			Hg	16.6 ± 22		
			K	0.37 ± 0.08	mg/L	
			Mg	0.9 - 3		
			Mo	5.8 ± 3.8		
			Na	4 - 6.69	mg/L	
			Pb	0.4 ± 0.5	μg/L	
			SO <sub>4</sub> <sup>2-</sup>	14.32 ± 0.54	mg/L	
			Th	6.6 ± 12.1	μg/L	
			U	5.4 ± 5.9		
			Zn	5.4 ± 2.6		
<b>Africa</b>						
Egypt	Baraka	1.5 L	Al	2.71	mg/L	(Saleh and others 2001)
			Ba	59.7		
			Ca	20.7		
			Co	0.02		
			Cr	8.92		
			Cu	4.63		
			Fe	79		
			Hg	0.01		
			K	21.2		
			Mg	23.3		
			Mo	1.86		
			Na	67.2		
			Ni	0.53		
			Pb	0.02		
			Sb	0.28		
			Si	17.2		
			Ti	60.8		
			V	2.51		
			Zn	4.85		
	Delta	Plastic 1.5 L	Al	3.51	mg/L	
			Ba	11.5		
			Be	0.02		
			Ca	27.2		
			Cd	0.02		
			Co	0.04		
			Cr	10.4		
			Cu	2.65		
			Fe	40.1		
			Hg	0.01		
			K	4.06		
			Mg	11.5		
			Mn	0.33		

(Continued)



Table 5–Continued

Country	Brand	Type of water	Parameter	Range	Unit	References
			Mo	0.88		
			Na	34.5		
			Ni	0.88		
			P	20.7		
			Pb	0.06		
			Sb	0.1		
			Si	17.1		
			Ti	80.4		
			V	7		
	Mineral	1.5 L	Zn	9.26		
			Ag	0.12	mg/L	(Saleh and others 2001)
			Al	13.3		
			Ba	40.1		
			Be	0.02		
			Ca	44.8		
			Cd	0.01		
			Co	0.04		
			Cr	14.9		
			Cu	10.5		
			Fe	121		
			Hg	0.03		
			K	4.88		
			Mg	1.54		
			Mn	0.05		
			Mo	0.35		
			Na	169		
			Ni	2.24		
			Pb	0.08		
			Sb	0.19		
			Si	11.5		
			Ti	136		
			V	4.59		
	Safi	1.5 L	Al	11.9	mg/L	
			Ba	262		
			Ca	7.88		
			Cr	5.45		
			Cu	2.92		
			Fe	60.9		
			Hg	0.01		
			K	21.2		
			Mg	8.15		
			Mn	1.41		
			Mo	0.29		
			Na	32.9		
			Ni	0.55		
			Pb	0.04		
			Sb	0.18		
			Si	12.3		
			Ti	23.4		
			V	1.51		
	Siwa	1.5 L	Zn	58.8	mg/L	
			Al	11		
			Ba	222		
			Be	0.01		
			Ca	6.02		
			Cd	0.01		
			Co	0.01		
			Cr	5.4		
			Cu	4.14		
			Fe	99.3		
			Hg	0.03		
			K	18.5		
			Mg	6.85		
			Mo	0.36		
			Na	43.8		
			Ni	1.24		
			P	3.92		
			Pb	0.2		
			Sb	0.3		
			Si	11.6		
			Ti	17.7		

(Continued)

Table 5—Continued

Country	Brand	Type of water	Parameter	Range	Unit	References
			V	1.49		
			Zn	64.1		
	Spa Reine	lm	Mg	1	mg/L	
			Na	3		

M = mineral; lm = low mineral content; mm = medium mineral content; hm = high mineral content; s = source; p = purified; c = carbonated; nc = noncarbonated; plastic = bottle made from synthetic material; glass = glass bottle.

Table 6—Levels of organic contaminants in bottled waters (literature information).

Parameter	Range	Type of water	Reference
<b>Pesticides</b>			
$\alpha$ -HCH	0.045–0.098 mg/L	Bottled 1.5–19 L	(Diaz and others 2009)
$\beta$ -HCH	0.048–0.152 mg/L		
$\beta$ -HCH	0.019–0.033 mg/L		
$\delta$ -HCH	0.012–0.046 mg/L		
Aldrin	0.012–0.027 mg/L		
DDD	0.003–0.009 mg/L		
DDE	0.029–0.060 mg/L		
DDT	0.003–0.009 mg/L		
Dieldrin	nd		
Endosulfan I	nd–0.005 mg/L		
Endosulfan II	nd		
Endosulfan sulfate	nd–0.033 mg/L		
Endrin	nd–0.008 mg/L		
Endrin aldehyde	0.001–0.007 mg/L		
<b>Volatile organic compounds</b>			
1,2,4-Trimethylbenzene	0.11–0.13 mg/L	Bottled	(Al-Mudhaf and others 2009, Ahmad and Bajahlan 2009, Ikem 2010)
1,2-Dichloropropane	0.12–0.4 mg/L		
1,3,5-Trimethylbenzene	0.41 mg/L		
1,3-Dichlorobenzene	0.1 mg/L		
Bromodichloromethane	0.1–0.58 mg/L		
Bromoform	0.11–37.55 mg/L		
Chloroform	0.1–1.85 mg/L		
Dibromochloromethane	0.1–1.76 mg/L		
Dibromomethane	0.1–0.74 mg/L		
Ethylbenzene	0.1–0.17 mg/L		
iso-Propylbenzene	0.11 mg/L		
Xylene	0.2–0.77 mg/L		
Naphthalene	0.1–0.75 mg/L		
Styrene	0.5–46.4 mg/L		
Toluene	0.1–1.18 mg/L		
Trichloroethene	0.13 mg/L		
Chloral-hydrate	0.4–0.9 $\mu$ g/L		
Trichloropropane	0.4–0.7 $\mu$ g/L		
Dichloroacetonitrile	0.12–0.22 $\mu$ g/L		
<b>Haloacetic Acids</b>			
Formic acid	33.2–58.1 $\mu$ g/L	Bottled (purified, mineral, natural)	(Liu and Mou 2003)
Dichloroacetic acid	na–0.6 $\mu$ g/L		
msp;Toluene	0.1–1.18 mg/L		
Ethanedioic acid	23–44 $\mu$ g/L		
<b>Antioxidant</b>			
Butylated hydroxytoluene	nd–38 $\mu$ g/L	Bottled 0.5–2 L	(Tombesi and Freije 2002)
4-Nonylphenol	108–298 ng/L	Bottled (mineral, pure)	(Li and others 2010)
Bisphenol A	17.6–324 ng/L		
Triclosan	0.6–9.7 ng/L		
<b>Perfluorochemicals</b>			
PFBuS	< 0.27 ng/L	Bottled	(Ericson and others 2008)
PFDA	0.63–0.82 ng/L		
PFDoDA	< 0.34 ng/L		
PFDS	< 0.1 ng/L		
PFHpA	0.4–0.61 ng/L		
PFHxA	0.87–0.102 ng/L		
PFHxS	< 0.18 ng/L		
PFNA	0.13–0.42 ng/L		
PFOA	0.16–0.67 ng/L		
PFOS	< 0.24 ng/L		
PFOSA	0.19 ng/L		
PFTDA	< 0.90 ng/L		
PFUnDA	< 0.43 ng/L		
THPFOS	< 0.1 ng/L		
<b>Carbonyl compounds</b>			
Formaldehyde	0.8–96.1 $\mu$ g/L	0.5–1.5 L, Bottled (c, nc)	(Nawrocki and others 2002)
Acetaldehyde	0.6–317.8 $\mu$ g/L		
Acetone	5.1–125.6 $\mu$ g/L		

c = carbonated; nc = noncarbonated.

## References

- Ahmad M, Bajahlan, AS. 2009. Quality comparison of tap waters vs. bottled water in the industrial city of Yanbu (Saudi Arabia). *Environ Monit Assess* 159:1–14.
- Al-Mudhaf HF, Alsharif FA, Aby-Shady A-S. 2009. A survey of organic contaminants in household and bottled drinking waters in Kuwait. *Sci Total Environ* 216:181–92.
- Al-Saleh UI, Al-Doush I. 1998. Survey of trace elements in household and bottled drinking water samples collected in Riyadh, Saudi Arabia. *Sci Total Environ* 216:181–92.
- Azoulay A, Garzon P, Eisenberg MJ. 2001. Comparison of the mineral content of tap water and bottled waters. *J Gen Intern Med* 16:168–75.
- Baba A, Ereeş FS, Hişönmez Ü, Çam S, Özdilek HG. 2007. An assessment of the quality of various bottled mineral water marketed in Turkey. *Environ Monit Assess* 139:277–85.
- Benefits of Recycling. Available from: <http://www.benefits-of-recycling.com/index.html> Accessed 2011 Jan.
- Bong YS, Ryu J-S, Lee K-S. 2009. Characterizing the origins of bottled water on the South Korean market using chemical and isotopic compositions. *Anal Chim Acta* 631:189–95.
- Burlingame B. 2003. Reflections on water. *J Food Compos Anal* 16:533–4.
- [PL-BN] Butelkowane wody stolowe: BN-90/9567-08, z dnia 28 lutego 1990 r.
- Chiba M, Shinohara A, Sekine M, Hiraishi S. 2006. Drinking water quality from the aspect of element concentrations. *J Radioanal Nucl Chem* 269:519–26.
- Coelho TM Castro R, Gobbo JA, Jr. 2011. PET containers in Brazil: opportunities and challenges of a logistics model for post-consumer waste recycling. *Res Conser Rec* 55:291–9.
- Costa ACM, Anjos MJ, Mortira S, Lopes RT, de Jesus EFO. 2003. Analysis of mineral water from Brazil using total reflection X-ray fluorescence by synchrotron radiation. *Spectrochim Acta B* 58:2199–204.
- de Beaufort ID. 2007. The camel syndrome. *J Public Health* 15:407–12.
- Diaz G, Ortiz R, Schettino B, Vega S, Gutierrez R. 2009. Organochlorine pesticides residues in bottled drinking water from Mexico City. *Bull Environ Contam Toxicol* 82:701–4.
- EEC. 1998. Council Directive 98/83/EC of 3rd November 1998 on the quality of water intended for human consumption. Official J L 330:32–54.
- EEC. 2003. Council Directive 2003/40/EC of 16 May 2003 establishing the list, concentration limits and labelling requirements for the constituents of natural mineral waters. Official J L 126:34–9.
- EPA Environmental Protection Agency. 2009. Current drinking water standards. Available from: <http://water.epa.gov/drink/contaminants/index.cfm>. Accessed Feb 2011.
- Ericson I, Nadal M, van Bavel B, Lindström G, Domingo JL. 2008. Levels of perfluorochemicals in water samples from Catalonia, Spain: is drinking water a significant contribution to human exposure? *Environ Sci Pollut Res* 15:614–9.
- FDA (Food and Drug Administration). 2010. Requirements for specific standardized beverages, Sec. 165.110 Bottled water. Available from: <http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?FR=165.110&st=drinking%20water>. Accessed Feb 2011.
- Greulich K, Alder L. 2008. Fast multiresidue screening of 300 pesticides in water for human consumption by LC-MS/MS. *Anal Bioanal Chem* 391:183–97.
- Güler C. 2007. Evaluation of maximum contaminant levels in Turkish bottled drinking water utilizing parameters reported on manufacturer's labeling and government-issued production licenses. *J Food Compos Anal* 20:262–72.
- Hansen HR, Pergantis SA. 2006. Detection of antimony species in citrus juices and drinking water stored in PET containers. *J Anal At Spectrom* 21:731–3.
- IBWA (International Bottled Water Association). 2009. Model bottled water regulation. Available from: [http://www.bottledwater.org/files/IBWA%20Code%20of%20Practice%20Updated%202009%20Final\\_3.pdf](http://www.bottledwater.org/files/IBWA%20Code%20of%20Practice%20Updated%202009%20Final_3.pdf). Accessed Feb 2011.
- Ikem A, Oduyungbo S, Egiebor NO, Nyavor K. 2002. Chemical quality of bottled waters from three cities in eastern Alabama. *Sci Total Environ* 285:165–75.
- Keresztes S, Tatar E, Miaucz VG, Virag I, Majdik C, Zaray G. 2009. Leaching of antimony from polyethylene terephthalate (PET) bottles into mineral water. *Sci Total Environ* 407:4731–5.
- Krachler M, Shoryk W. 2009. Trace and ultratrace metals in bottled waters: survey of sources worldwide and comparison with refillable metal bottles. *Sci Total Environ* 407:1089–96.
- Leivadara SV, Nikolaou AD, Lekkas TD. 2008. Determination of organic compounds in bottled waters. *Food Chem* 108:277–86.
- Li X, Ying G-G, Su H-C, Yang X-B, Wang L. 2010. Simultaneous determination and assessment of 4-nonylphenol, bisphenol A and triclosan in tap water, bottled water and baby bottles. *Environ Intern* 36:557–62.
- Liu Y, Mou S. 2003. Simultaneous determination of trace level bromate and chlorinated haloacetic acids in bottled drinking water by ion chromatography. *Microchem J* 75:79–86.
- Liu Y, Mou S. 2004. Determination of bromate and chlorinated haloacetic acids in bottled drinking water with chromatographic methods. *Chemosphere* 55:1253–8.
- Morr S, Cuartas E, Alwattar B, Lane JM. 2006. How much calcium is in your drinking water? A survey of calcium concentrations in bottled and tap water and their significance for medical treatment and drug administration. *HSSJ* 2:130–5.
- Nawrocki J, Dąbrowska A, Borcz A. 2002. Investigation of carbonyl compounds in bottled waters from Poland. *Water Res* 36:4893–901.
- Petraccia L, Liberati G, Masciullo SG, Grassi M, Fraioli A. 2006. Water, mineral waters and health. *Clin Nutr* 25:377–85.
- PL - BN (Polish legalization Dz. U. Nr 276, poz. 2738) 2004. Available from: <http://www.abc.com.pl/serwis/du/2004/2738.htm>. Accessed Feb 2011.
- Polkowska Z. 2003. Determination of selected tap water components in a large urban agglomeration (Gdansk). *Ecol Chem Eng* 10:335–50.
- Rosborg I, Nihlga B, Gerhardsen L, Gernersson M-L, Ohlin R, Olsson T. 2005. Concentrations of inorganic elements in bottled waters on the Swedish market. *Environ Geochem Health* 27:217–27.
- Saad B, Pok FW, Sujari ANA., Saleh MI. 1998. Analysis of anions and cations in drinking water samples by capillary ion analysis. *Food Chem* 61:249–54.
- Saleh M, Ewane E, Jones J, Wilson B. 2001. Chemical evaluation of commercial bottled drinking water from Egypt. *J Food Compos Anal* 14:127–52.
- Schmid P, Kohler M, Meierhofer R, Luzzi S, Wegelin M. 2008. Does the reuse of PET bottles during solar water disinfection pose a health risk due to the migration of plasticisers and other chemicals into the water? *Water Res* 42:5054–60.
- Shi Y, Zhang P, Wang Y, Shi J, Cai Y, Mou S, Jiang G. 2007. Perchlorate in sewage sludge, rice, bottled water and milk collected from different areas in China. *Environ Intern* 33:955–62.
- Shoty W, Krachler M. 2007a. Contamination of bottled waters with antimony leaching from polyethylene terephthalate (PET) increase upon storage. *Environ Sci Technol* 41:1560–3.
- Shoty W, Krachler M. 2007b. Lead in bottled waters: contamination from glass and comparison with pristine groundwater. *Environ Sci Technol* 41:3508–13.
- Tombesi NB, Freije H. 2002. Application of solid-phase microextraction combined with gas chromatography–mass spectrometry to the determination of butylated hydroxytoluene in bottled drinking water. *J Chrom A* 963:179–83.
- USDA (U.S. Department of Agriculture). 2000. Biotechnology: USDA's Role. Washington, D.C.: U.S. Dept. Agriculture. Available from: [www.usda.gov](http://www.usda.gov). Accessed Jan 27, 2002.
- van der Aa M. 2003. Classification of mineral water types and comparison with drinking water standards. *Environ Geol* 44:554–63.
- Westerhoff P, Prapaipong P, Shock P, Hillaireau A. 2008. Leaching of antimony from polyethylene terephthalate (PET) plastic using for bottled drinking water. *Water Res* 42:551–6.
- WHO (World Health Organization). 2008. Draft third edition of the WHO guidelines for drinking—water quality. Available from: [http://www.who.int/water\\_sanitation\\_health/dwq/fulltext.pdf](http://www.who.int/water_sanitation_health/dwq/fulltext.pdf). Accessed Feb 2011.

