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Chemical quality of bottled waters from three cities in eastern Alabama

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Abstract

Twenty-five brands of bottled waters consisting of both purified and spring types collected randomly from three Alabama cities, USA were assessed for their suitability for human consumption. Water quality constituents analyzed include pH, conductivity, alkalinity, chloride, nitrate + nitrite, sulfate, phosphate, total carbon (TC), inorganic carbon (IC), total organic carbon (TOC), and 27 elements on the inductively coupled plasma-optical emission spectrometer (ICP-OES). The results obtained were compared with US EPA drinking water standards and the European union (EU) drinking water directive. Ni was non-detectable in all the samples and Cu, Pb, Sb, Zn, Mn, Al, Cr, Mg, P, Ca, sulfate, chloride and nitrates + nitrites were all below their respective USEPA drinking water standards or EU maximum admissible concentrations (MAC). The conductivity, pH, As, Cd, Hg, Zn, Se and Tl values in some samples exceeded the EU and USEPA standards for drinking water. No sample had $pH > 8.5$, but seven bottled water brands analyzed were acidic ($pH < 6.5$). Most of the sampled brands had TOC concentrations exceeding 3 mg/l. The concentrations of most water quality constituents analyzed, in most cases, were higher in the spring water brands compared to the purified or distilled brands of bottled water. A one-way parametric analysis of variance (ANOVA) conducted on pH, conductivity, IC, TOC, Ca, Na, K, Mg, Se, sulfate, chloride and nitrate + nitrite values for 10 brands of bottled water to ascertain the homogeneity of variances within and between the brands, suggested significant differences in variances across the brands at a 95% confidence level except for selenium, sodium and calcium. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Bottled water; Water quality constituents; Inductively coupled plasma (ICP-OES); Drinking water standards; Maximum admissible concentrations (MAC); ANOVA; Brands

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1. Introduction

There is increasing concern worldwide about the quality of drinking water (Ozturk and Yilmaz, 2000; Gulson et al., 1997). Literature reveals that the levels of some water quality constituents in drinking waters are in violation of action levels for various parameters, especially some toxic trace metals (Ozturk and Yilmaz, 2000; Frengstad et al., 2000; Misund et al., 1999; Al-Saleh and Al-Doush, 1998; Asubiojo et al. 1997; Reimann et al., 1999; Auslander and Langlois, 1993). The sale and consumption of bottled waters is on the increase both in the USA (Calabrase, 1997; Allen and Darby, 1994; Allen et al., 1989) and in other parts of the world (Misund et al., 1999). Concern over its adequacy for mass consumption is also on the increase (Allen and Darby, 1994). Assessment of bottled waters collected in Canada (Pip, 2000), Europe (Misund et al., 1999), Mexico (Robles et al., 1999) and Saudi Arabia (Al-Saleh and Al-Doush, 1998) and USA (Allen et al., 1989) reported violation of some drinking water permissible limits. The presence of organics, toxic elements, radionuclides, nitrates and nitrites in drinking water can lead to cancer, other human body malfunctions and chronic illnesses (Kuo et al., 1997; Parslow et al., 1997; Aral et al., 1996; Tzezou et al., 1996; National Research Council, 1997; Hoxie et al., 1997). Bottled water can be the source of the causative agent in cholera, typhoid outbreaks and traveler's disease. Also, bacteria (the most common pathogen) have been found at various stages in the production of bottled water (Warburton, 1993) and from commercial bottled water samples (Nsanze et al., 1999; Penland and Wilhelmus, 1999). There may be considerable risk to humans, especially children exposed to bottled water containing toxic elements and microbiological entities. It is known that children may be exposed due to their behaviors, greater gastrointestinal absorption, and a lower threshold for adverse effects (Cambra and Alonso, 1995).

Bottled water is widely consumed because it is inexpensive, readily available, tastes better, contains fewer impurities and confers a higher social status on the consumer than tap water. Apart from the use of bottled water as drinking water, it has found wide usage in infant formula preparation and reconstituting other foods, for cleaning contact lenses, for skin care and for filling humidifiers (Warburton, 1993). Bottled waters pass through treatment processes such as filtration, deionization, reverse osmosis, and ozonation (Allen et al., 1989) to ensure its quality, but poor quality control during production can contaminate this widely consumed resource.

The routine monitoring of drinking water can assure the populace that the quality of their drinking water is adequate. It can also be beneficial in detecting deterioration in the quality of drinking water and facilitate appropriate timely corrective actions with minimal negative impact on the health of the populace. In this study, the major aims are: (1) to characterize various bottled water brands for water quality constituents and compare the levels obtained with US EPA drinking water standards/EU drinking water directive; (2) to compare the quality of spring water and the purified or distilled bottled water types; and finally (3) to statistically test the variability of the water quality constituents across the bottled water brands.

2. Material and methods

2.1. Reagents

All chemicals used were of reagent grade and were purchased from Fisher Scientific (Suwanee, GA, USA) and Hach (Loveland, CO, USA). Distilled water was used as feed water to produce ultra pure deionized water from the Nanopure Infinity UV/UF Deionizer (Barnstead Thermolyne, IA, USA). The deionized water used throughout the period of experimentation had less than 1 $\mu g/l$ organics and a resistivity of 18.3 $m\Omega/cm$ at room temperature. One hundred mg/l of mixed standards containing a suite of elements were obtained from SPEX Certiprep, Inc (Metuchen, NJ, USA). Other 1000-mg/l metal standards used were purchased through Fisher Scientific. The ICP-OES was calibrated by preparing calibration standard solutions from the stock standard solutions and an internal standard (scandium) was used as part of the quality assurance. SRM 1640 was used to check the accuracy and precision of the analytical method. Standard reference material (SRM 1640: trace elements in natural water) was purchased from National Institute of Standards and Technology (NIST), Gaithersburg, MD, USA.

2.2. Sample collection

Twenty-five brands of bottled water consisting of spring and purified bottled water types (Table 1) were purchased randomly from different supermarket stores in three Alabama cities (Tuskegee, Auburn and Montgomery), USA and assessed for good quality. The samples were purchased and analyzed between July 1999 and May 2000. All the brands were in plastic containers with plastic screw caps except the Perrier bottled water brand in a 750-ml glass container with a metal screw cap. The bottled water capacity of the samples purchased ranged between 0.5 and 1.5 l. Table 1 presents the classification of the bottled waters in terms of brands, bottled water types and sample container types.

2.3. Analytical methodology and quality assurance

Bottled water samples were transported to the laboratory where most water quality constituents were determined within 2–6 h after purchase of samples. The bottled samples collected did not contain particulates. Thus, samples were not filtered prior to analyses for various parameters. The pH and conductivity were measured with MultiLab P4 (Multiparameter Instrument) (Wissenschaftlich-Technische Werkstatten GmbH, Weilheim, Germany) after calibration with standard pH buffers and conductivity standard solutions. Alkalinity measurement was by titration (APHA, 1998); chloride was by argentometric procedure (APHA, 1998); sulfate by turbidimetric method (APHA, 1998); phosphate by ascorbic acid method (APHA, 1998); and total nitrate + nitrite by cadmium reduction method (Hach, 1998). For the metals determination, Ethos Plus microwave Labstation (Milestone Inc., Monroe, CT 06468, USA) was used to digest samples using EPA method 3015 for water. HNO_3 (5 ml) was added to a 45-ml sample in a washed microwave digestion vessel and the microwave program below was employed: step 1: 160°C for 10 min at 1000 W; and step 2: 165°C for 10.0 min at 1000 W. Digests were made up and aspirated into calibrated Perkin-Elmer DV 3300 ICP-OES. Elements determined were Ag, Al, As, Be, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Mg, Mn, Mo, Na, Ni, Pb, Sb, Se, Sn, Ti, Tl, V, Zn, Th and U. The ICP-OES instrument operating conditions are presented in Table 2. Also, the linear concentration range and detection limits for an axially viewed ICP-OES is presented in Table 3. As part of the quality control protocol, analysis of reagent blanks; method blanks and certified reference water SRM 1640 were carried out on the ICP-OES. Table 4 presents the result of the analysis of NIST SRM 1640: trace elements in water. The result of the analysis of SRM 1640 was generally in agreement with NIST certified values.

Other water quality parameters determined in the bottled water samples were total carbon (TC), inorganic carbon (IC), and total organic carbon (TOC). TC, IC and TOC in four samples assigned to three brands were not determined. Two samples of the Perrier brand and a sample of Poland-spring brand were carbonated. In addition, the cherry brand was not analyzed for TC, IC and TOC because the sample contained high fructose corn syrup, citric acid and potassium benzoate. TC, IC and TOC measurements were carried out with DC-180 Carbon Analyzer (Rosemount Analytical Inc., CA, USA). The analyzer utilized potassium persulfate, oxygen and UV to breakdown the organics to CO_2, which was measured by an IR detector. The analyzer was calibrated for TC and TOC with potassium hydrogen phthalate. Standard addition experiments on the TOC analyzer were conducted and the percentage recoveries for the known additions using the TOC analyzer ranged between 89.2% and 105.4%.

2.4. Statistical analysis

A one-way analysis of variance (ANOVA)

Table 1
Classification of bottled waters

Brand code	Brand name	Bottled water type	Container type	Number analyzed
1	Aberfoyle	Spring water	Plastic	1
2	Aquafina	Purified	Plastic	7
3	Canterbury	Spring water	Plastic	1
4	Cherry spring	Spring water	Plastic	1[a]
5	Crystal Geyser	Spring water	Plastic	2
6	Crystal springs	Spring water	Plastic	4[b]
7	Dannon	Spring water	Plastic	3[b]
8	Dasani	Purified	Plastic	11[b]
9	Evian	Spring water	Plastic	1
10	Fountainhead	Spring water	Plastic	6[b]
11	Goldemb	Spring water	Plastic	1
12	Hawaiian	Spring water	Plastic	1
13	Melwood	Spring water	Plastic	2
14	Mountainvalley	Spring water	Plastic	1
15	Oasis	Spring water	Plastic	2
16	Perrier	Spring water	Glass	2[c]
17	Pleasantspring	Spring water	Plastic	1
18a	Polandspring	Spring water	Plastic	5[b]
18b	Polandspring	Spring water	Plastic	1[c]
19	Prestige	Spring water	Plastic	2
20	Sams	Purified	Plastic	1
21	Silverspring	Spring water	Plastic	3[b]
22	Southernhome	Spring water	Plastic	4[b]
23	Springtime	Spring water	Plastic	3[b]
24	Sweetwater	Spring water	Plastic	2
25	Zephyrhills	Spring water	Plastic	5[b]

[a] Cherry flavored and contained high fructose corn syrup, citric acid and potassium benzoate.
[b] Analysis of variance (ANOVA) was carried out on 10 brands at 95% confidence level to ascertain significant differences across the brands. Three samples per brand were selected from brands with sample number ≥ 3.
[c] Carbonated bottled water.

procedure was applied on the analytical data obtained to determine if the variances across the brands were homogenous. The parameters considered were pH, conductivity, total alkalinity, IC, TOC, Ca, Na, K, Mg, Se, sulfate, chloride and nitrate + nitrite. The ANOVA was conducted on brands 2, 6, 7, 8, 10, 18, 21, 22, 23 and 25 (purified and spring type waters) and brands 6, 7, 10, 18, 21, 22, 23 and 25 (spring type waters only). Each brand was represented by three samples collected randomly from various locations. The one-way parametric ANOVA procedure (at 95% confidence level) was adopted since it has been adjudged to be a preferred method compared to non-parametric procedures, especially when the percentage of non-detects is less than 15% (McBean and Rovers, 1998).

3. Results and discussion

3.1. Characteristics of bottled waters

The bottled water chemical characteristics were compared with the European Union (EU) maximum permissible directive and US EPA drinking water standards (Table 5). The EU and US EPA standards for drinking water were used since some of the bottled waters were imports from Europe and some guideline levels were lacking in the US EPA standards. Table 6 presents the summary of the water quality data obtained for the bottled water brands. Most water quality constituents in the brands analyzed were within acceptable limits when compared with the EPA standards or EU directives. The trace metals were in the parts per billion (ppb) range, but some of the brands posted values above the respective detection limits.

From Table 6, three brands had conductivity values exceeding the EU guide value of 400 μS/cm stipulated for drinking water. Some samples assigned to brands 2, 4, 6, 8, 16, 18a, 18b and 20 were acidic based on the pH drinking water standard (pH < 6.5). Only Perrier (brand 16) and Polandsprings (brand 18) bottled waters were carbonated. The most acidic brand was a cherry flavored bottled water sample (brand 4) with a pH of 2.8. The cherry brand contained citric acid. All the brands analyzed had nitrate + nitrite levels below the US EPA 50 mg/l recommended guideline for nitrate + nitrite in drinking water. Although no brand had a high nitrate + nitrite content above the action level, the presence of nitrates and nitrites in drinking water at unacceptable levels causes shortness of breath, blue babies syndrome in infants, diuresis and hemorrhaging of spleen (US EPA, 1998a).

Most sampled brands had TOC concentrations greater than 3 mg/l, which is considered the maximum level for relatively clean waters (McNeely et al., 1979). The 3-mg/l TOC level used is not necessarily a standard for drinking waters. The purified bottled water brands (brands 2, 8 and 20) had lower TOC values compared to the

Table 2
Instrument operating parameters applied for metals determination by ICP-OES

Parameters	
Plasma view mode	Axial
Gas	Argon
Shear gas	Nitrogen
Gas: plasma	15 l/min
Gas flow: Auxiliary	0.5 l/min
Nebulizer	0.8 l/min
Source equilibration time	15 s
Pump speed	18.75 rev./min
Pump flow rate	1 ml/min
Detector	Charge array
RF power	1300 W
Sample aspiration rate	1 ml/min
Peak algorithms and points/peaks	Peak height
View height	15 mm
Number of replicates	3
Background correction	Manual point correction
Read delay	120 s
Rinse delay	20 s

Table 3
Linear concentration range and detection limits for an axially viewed optima

Element	Wavelength	Typical DL (μg/l, 3σ)	Upper linear concentration (mg/l)
Ag	328.068	0.4	20
Al	308.215	4	500
Al	396.152	2	500
As	189.042	2	10
As	193.696	5	10
B	249.678	0.5	
Ba	455.403	0.07	40
Be	313.042	0.08	5
Bi	223.061	2	
Ca	317.933	2	500
Cd	214.438	0.3	10
Cd	226.502	0.2	10
Cd	228.802	0.3	10
Co	228.616	0.5	10
Co	238.892	0.4	10
Cr	205.552	0.4	40
Cr	206.149	0.6	40
Cr	267.716	0.2	40
Cu	324.754	0.5	50
Cu	327.396	0.2	50
Fe	238.204	0.5	200
Fe	259.940	0.3	200
Hg	194.168	0.5	
K	766.491	2	100
Mg	279.553	0.05	500
Mn	257.610	0.1	50
Mo	202.030	0.7	
Na	589.592	3	500
Ni	221.647	0.9	50
Ni	231.604	0.7	50
Pb	220.353	0.8	50
Sb	206.838	2	100
Sb	217.581	2	100
Se	196.026	2	10
Sr	421.552	0.1	
Ti	334.941	0.7	
Ti	337.000	0.2	
Ti	190.864	0.2	
V	292.402	0.4	50
Zn	202.548	0.3	50
Zn	206.200	0.5	50
Zn	213.856	0.1	50

Source: Perkin-Elmer Corporation, 1997.

spring water brands. The presence of toxic organic compounds at low concentrations in drinking water may create human health impairment. Plant and animal materials contribute organic carbon to the aquatic environment. The contamination of groundwater as a result of runoffs from agricultural lands and from municipal and industrial discharges may further increase the levels of TOC in water (McNeely et al., 1979). In addition, organic compounds in water may react with disinfectants to produce potentially toxic and carcinogenic compounds (APHA, 1998). Also the presence of natural organic matter (NOM) may increase the level of TOC in drinking water.

Phenolphthalein alkalinity was zero in all the brands analyzed and total alkalinity in the various brands was due to bicarbonate. Brands 15 and 24 exceeded the EU directive for sodium in drinking water. Sodium-rich waters may be detrimental to the health of heart patients (US EPA, 1998b) and sodium contributes to the occurrence of hypertension (Garzon and Eisenberg, 1998). Low salt diet patients may be affected by high ingestion of sodium rich waters. The levels of potassium in three brands were above the EU guideline value of 12 mg/l stipulated for drinking water (Table 6). Cadmium concentrations in five bottled water brands (brands 6, 16, 19, 21 and 22) exceeded the stipulated guideline value for Cd in drinking water. Cadmium ingestion above the drinking water action level can cause nausea, vomiting, salivation, sensory disturbances, liver injury, shock and renal failure in the short term; and in the long term, can cause kidney, liver, bone and blood damage as a result of a lifetime exposure at levels

Table 4
SRM 1640: Trace elements in natural water

Element	NIST certified values for SRM 1640	ICP-OES Wavelengths	Measured values
Aluminum (μg/l)	52 ± 1.5	308.215	50.2 ± 3.46
Antimony (μg/l)	13.79 ± 0.42	206.836	13.1 ± 2.48
Arsenic (μg/l)	26.67 ± 0.41	188.979	23 ± 6.6
Barium (μg/l)	148.0 ± 2.2	455.403	134 ± 2.9
Beryllium (μg/l)	34.94 ± 0.41	313.107	31.3 ± 0.17
Boron (μg/l)	301 ± 6.1	–	na
Cadmium (μg/l)	22.79 ± 0.96	226.502	19.4 ± 0.38
Chromium (μg/l)	38.6 ± 1.6	267.716	32.9 ± 1.25
Cobalt (μg/l)	20.28 ± 0.31	238.892	19.1 ± 0.59
Copper (μg/l)	85.2 ± 1.2	324.752	86.2 ± 1.13
Lithium (μg/l)	50.7 ± 1.4	610.362	53.0 ± 3.1
Nickel (μg/l)	27.4 ± 0.8	231.604	22.0 ± 0.47
Potassium (μg/l)	994 ± 27	766.490	1120 ± 33.1
Rubidium (μg/l)	2.00 ± 0.02	–	na
Zinc (μg/l)	53.2 ± 1.1	213.857	48.2 ± 0.19
Iron (μg/l)	34.3 ± 1.6	259.939	33.1 ± 0.74
Lead (μg/l)	27.89 ± 0.14	220.353	18.3 ± 0.96
Manganese (μg/l)	121.5 ± 1.1	257.610	111 ± 1.2
Molybdenum (μg/l)	46.75 ± 0.26	202.031	45.5 ± 0.56
Selenium (μg/l)	21.96 ± 0.51	196.026	15.9 ± 2.32
Silver (μg/l)	7.62 ± 0.25	328.068	6.5 ± 0.42
Strontium (μg/l)	124.2 ± 0.7	421.552	112 ± 2.2
Vanadium (μg/l)	12.99 ± 0.37	292.402	12.1 ± 1.17
Calcium (mg/l)	7.045 ± 0.089	317.933	6.44 ± 0.10
Magnesium (mg/l)	5.819 ± 0.056	279.077	5.81 ± 0.09
Silicon (mg/l)	4.73 ± 0.12	212.412	5.52 ± 0.09
Sodium (mg/l)	29.35 ± 0.31	330.237	28.5 ± 0.57

na: not analyzed.

Table 5
EU and US EPA drinking water standards

Parameter	EU[a] MAC[e]	USEPA[b] MCL[†] or SMCLs[‡] (mg/l)
pH	6.5 < pH < 8.5 GV*	6.5–8.5
Conductivity	400 μS/cm GV	–
Color		15 color units
Corrosivity	–	non-corrosive
Odor	–	3 threshold odor numbers
Foaming agents	–	0.5 mg/l
Total Dissolved Solids (TDS)	–	500 mg/l
Fluoride	–	2.0 mg/l[d]
Sulfates	250 mg/l SO_4^{2-}	500 mg/l
Chloride	–	250 mg/l
Nitrate + nitrite	–	10 mg/l
Calcium	100 mg/l Ca GV	–
Magnesium	50 mg/l Mg	–
Sodium	150 mg/l Na	–
Potassium	12 mg/l K	–
Aluminum	0.2 mg/l Al	0.05–0.2 mg/l
Boron	1000 μg/l B GV	–
Iron	200 μg/l Fe	0.3 mg/l
Manganese	50 μg/l Mn	0.05 mg/l
Copper	100 μg/l Cu GV	1.0 mg/l
Zinc	100 μg/l Zn GV	5 mg/l
Phosphorus	5000 μg/l P_2O_5/L	–
Barium	100 μg/l Ba GV	–
Arsenic	50 μg/l As	10 μg/l[c]
Cadmium	5 μg/l Cd	–
Chromium	50μg/l Cr (Total)	–
Mercury	1 μg/l Hg	–
Nickel	50 μg/l Ni	–
Lead	50 μg/l Pb	–
Antimony	10 mg/l Sb	–
Selenium	10 mg/l Se	0.05 mg/l
Thallium	–	0.002 mg/l
Radon	–	300 Ci/l
Uranium	–	20 μg/l

[a]Source: Kiely, 1997; [b]Source: US EPA, 1996; [c]Source: US EPA, 2001; [d]Under review by US EPA; *GV = guide value; [e]MAC = maximum admissible concentration; [†]MCL = maximum contaminant level; [‡]SMCLs = secondary maximum contaminant level.

above the maximum contaminant level (US EPA, 1998c). Nickel was non-detectable in all the brands and Cu, Pb, Sb, Zn, Mn, Al, Cr, Mg, P, Ca, sulfate and chloride were all below their respective US EPA drinking water standards or EU maximum admissible concentrations. Brand 9 had the highest level of magnesium (27.3 mg/l). It is beneficial to have magnesium-rich drinking water. Epidemiological and clinical studies suggest that magnesium may reduce the frequency of sudden death in humans (Garzon and Eisenberg, 1998).

Eleven samples from five bottled water brands (brands 2, 6, 8, 10 and 18) had arsenic concentrations exceeding the US EPA limit of 10 μg/l in drinking water (US EPA, 2001) and the maximum arsenic concentration recorded was 29 μg/l. A high concentration of arsenic in drinking water increases stillbirths and spontaneous abortion, causes arsenism and black foot disease, hyper pigmentation, cardiovascular diseases and skin cancer (Jain and Ali, 2000; US EPA, 1998a; WHO, 1981). Most of the brands analyzed had mercury levels above 1 μg/l and the potential health effects from ingestion of water with high mercury content may lead to kidney damage (US EPA, 1998a). Twenty-one samples from 14 brands had thallium levels above the 2-μg/l guideline and thorium concentrations in a number of samples exceeded 2 μg/l. The maximum value reported for thorium was 32 μg/l, but the health effect of ingestion of thorium is not known. One sample assigned to brand 8 exceeded the uranium drinking water standard of 20 μg/l recommended by US EPA. The maximum uranium level recorded in this study was 22 μg/l. No brand exceeded the stipulated EU guideline value of 10 mg/l for Se, but brand 4 (a cherry flavored spring bottled water sample) violated the US EPA standard of 0.05 mg/l Se in drinking water. Ingestion of selenium above the action levels may cause hair or fingernail loss, numbness in fingers or toes and circulatory problems (US EPA, 1998a).

3.2. Comparison of spring and purified bottled waters

There were differences in the concentrations of the various parameters determined for the two types of bottled waters (spring and purified bottled water types). The purified or distilled brands contained less dissolved materials than the spring types. In most cases, the spring bottled waters had higher values of conductivity, TC, IC, TOC, chloride, total alkalinity, nitrate + nitrite, K, Mg, Mn, Se, Zn, P, Mo, Sn, Tl, V, As and Ag than the purified brands (Table 6).

3.3. ANOVA of bottled water brands

The ANOVA result for 10 bottled water brands (brands 2, 6, 7, 8, 10, 18, 21, 22, 23 and 25) suggests that the variances of pH, conductivity, total alkalinity, IC, TOC, K, Mg, sulfate, chloride and nitrate + nitrite were statistically unequal at a 95% confidence level. However, the variances of calcium, sodium and selenium were found to be homogenous across the brands. Also, one-way parametric ANOVA conducted on eight brands (brands 6, 7, 10, 18, 21, 22, 23 and 25) that were spring type bottled waters, suggests a similar result to that obtained above. The non-homogeneity of variances across the brands may be largely due to the disparity in the concentrations of dissolved materials across the bottled water brands.

4. Conclusions

Some bottled water samples had values of pH, conductivity, essential and non-essential elements exceeding the EU and US EPA drinking water standards. These samples may not be suitable for human consumption. The notion that natural spring water is absolutely clean may be wrong since many toxic elements and organics may be present in mineral waters due to pollution effects

Table 6
Chemical quality of bottled water brands

Brand	*n*	pH	Conductivity (μS/cm)	TC (mg/l)	IC (mg/l)	TOC (mg/l)	Ag (μg/l)	Al (μg/l)	As (μg/l)	Pb (μg/l)
1	1	7.49	577	58.18	15.84	42.34	Nd	4	Nd	Nd
2	7	5.75 ± 0.42	6.13 ± 2.04	2.00 ± 1.11	0.35 ± 0.42	1.65 ± 1.16	1.1 ± 1.9	1.3 ± 2.9	11.9 ± 9.1	0.3 ± 0.7
3	1	8.13	268.8	34.9	10.14	24.76	Nd	Nd	Nd	Nd
4	1	2.8	666	Na	Na	Na	Nd	Nd	Nd	Nd
5	2	8.06 ± 0.0	246.4 ± 20.79	23.38 ± 15.36	8.76 ± 1.00	14.62 ± 14.36	1.0 ± 1.1	3 ± 4.2	Nd	Nd
6	4	6.79 ± 0.81	53.75 ± 75.90	7.43 ± 10.73	1.96 ± 2.73	5.45 ± 8.02	50 ± 27	0.2 ± 0.5	12 ± 10.7	0.5 ± 1
7	3	7.84 ± 0.12	359.93 ± 27.52	23.84 ± 11.42	6.31 ± 3.05	17.54 ± 8.38	0.3 ± 0.6	2.7 ± 2.5	Nd	0.3 ± 0.5
8	11	6.32 ± 0.31	51.57 ± 4.41	2.55 ± 0.80	0.94 ± 0.8	1.61 ± 0.88	0.2 ± 0.4	2.6 ± 4.2	6.5 ± 6.3	0.3 ± 0.5
9	1	7.08	515	78.06	71.38	6.68	Nd	0.006	Nd	Nd
10	6	7.61 ± 0.35	77.32 ± 5.15	6.11 ± 2.13	2.73 ± 1.67	3.38 ± 2.59	67.8 ± 161.3	4.7 ± 5.6	9.7 ± 11.4	0.2 ± 0.4
11	1	7.65	131.9	5.72	3.11	2.61	0.12	Nd	4	Nd
12	1	8.01	95.6	8.85	2.65	6.2	2	Nd	Nd	Nd
13	2	7.71 ± 0.20	144.75 ± 78.84	16.26 ± 6.00	4.53 ± 2.09	11.73 ± 3.92	3 ± 2.8	6.5 ± 9.2	2 ± 2.8	Nd
14	1	7.8	385	49.6	12.4	37.2	Nd	Nd	Nd	Nd
15	2	7.34 ± 1.13	125.8 ± 136.47	11.86 ± 11.7	2.91 ± 3.45	8.95 ± 8.27	Nd	2.5 ± 3.5	2.5 ± 3.5	Nd
16	2	5.53 ± 0.05	731 ± 62.23	Na	Na	Na66 ± 93.3	Nd	Nd	Nd	
17	1	7.79	213.6	23.3	7.01	16.29	1	Nd	Nd	Nd
18a	5	6.9 ± 0.69	69.68 ± 12.58	6.10 ± 1.78	1.27 ± 0.48	4.83 ± 1.32	3.0 ± 6.2	0.4 ± 0.9	4.2 ± 9.4	1.2 ± 1.6
18b	1	4.32	93.3	Nd	Nd	Nd	92	Nd	Nd	Nd
19	2	8.03 ± 0.01	233.4 ± 19.80	13.97 ± 8.17	5.38 ± 0.01	8.59 ± 8.15	Nd	1.0 ± 1.4	Nd	Nd
20	1	5.04	27.5	0.69	0.21	0.48	1	Nd	0.005	3
21	3	8.03 ± 0.07	238.8 ± 16.89	12.84 ± 7.16	5.41 ± 0.06	7.43 ± 7.13	8.3 ± 14.4	0.3 ± 0.6	Nd	Nd
22	4	7.70 ± 0.11	353 ± 19.36	37.49 ± 17.7	9.64 ± 4.95	27.85 ± 17.9	0.5 ± 1	Nd	Nd	Nd
23	3	6.70 ± 0.24	78.9 ± 3.06	12.45 ± 0.96	5.26 ± 4.59	7.19 ± 3.67	0.3 ± 0.6	0.3 ± 0.6	1 ± 1.7	Nd
24	2	7.14 ± 0.04	123.6 ± 3.96	10.31 ± 0.11	2.51 ± 0.16	7.80 ± 0.26	0.5 ± 0.7	Nd	Nd	0.5 ± 0.7
25	5	7.98 ± 0.24	340.8 ± 31.4	31.56 ± 10.8	10.4 ± 0.72	21.1 ± 10.4	11.4 ± 25.5	0.6 ± 0.9	0.8 ± 1.8	0.4 ± 0.5

Table 6 (*Continued*)

Brand	*n*	Ca (mg/l)	Cd (μg/l)	Co (μg/l)	Cr (μg/l)	Cu (μg/l)	Fe (mg/l)	K (mg/l)	Mg (mg/l)	Mn (μg/l)	Mo (μg/l)
1	1	0.05	< 0.2	1	< 0.2	1	0.001	1.82	24.5	< 0.1	< 0.7
2	7	0.06 ± 0.04	1 ± 1.9	2 ± 1.5	< 0.2	0.6 ± 0.8	0.1 ± 0.4	0.05 ± 0.05	0.02 ± 0.03	0 ± 0	2.3 ± 4.7
3	1	0.05	< 0.2	< 0.4	< 0.2	1	0.001	1.79	16	1	1
4	1	0.04	< 0.2	0.002	< 0.2	1	0.003	63.2	3.2	< 0.1	2
5	2	18.92 ± 26.7	2 ± 2.8	1 ± 1.4	< 0.2	< 0.2	0.001 ± 0.001	1.13 ± 0.25	5.50 ± 0.93	0.5 ± 0.7	1 ± 1.4
6	4	4.34 ± 8.58	3 ± 3.6	0.8 ± 1.5	< 0.2	< 0.2	0.8 ± 0.5	0.52 ± 0.23	2.75 ± 4.48	5.5 ± 3.7	5 ± 8.0
7	3	21.95 ± 22.45	0 ± 0	1.7 ± 1.5	0.3 ± 0.5	0.7 ± 0.6	0.001 ± 0.001	1.09 ± 0.91	7.10 ± 2.84	0 ± 0	0 ± 0
8	11	0.08 ± 0.12	0.7 ± 1.6	1.5 ± 1.4	0.4 ± 0.9	0.5 ± 0.6	0.4 ± 0.6	2.55 ± 0.47	3.10 ± 0.77	2 ± 7	2.7 ± 3.5
9	1	0.05	< 0.2	1	< 0.2	< 0.2 < 0.0005	1.09	27.3	1	5	
10	6	3.10 ± 4.74	1.3 ± 2.2	1 ± 0.8	< 0.2	0.5 ± 0.8	0.001 ± 0.0006	1.30 ± 0.19	0.34 ± 0.04	0 ± 0	2.8 ± 3.1
11	1	0.05	5	Nd	< 0.2	< 0.2	0.001	0.258	3.2	1	2
12	1	0.04	< 0.2	Nd	< 0.2	1	0.009	2.35	3.47	1	2
13	2	1.53 ± 2.10	0 ± 0	1 ± 1.4	< 0.2	1.5 ± 0.7	0.001 ± 0	10.2 ± 8.77	1.06 ± 0.92	0.5 ± 0.7	3 ± 4.2
14	1	0.05	< 0.2	Nd	< 0.2	2	0.003	1.22	8.15	1	2
15	2	0.05 ± 0	0 ± 0	0.5 ± 0.7	< 0.2	0.5 ± 0.7	0 ± 0	0.58 ± 0.22	4.39 ± 4.34	0 ± 0	10 ± 11.3
16	2	0.04 ± 0	3.5 ± 4.9	1 ± 1.4	< 0.2	< 0.2	0.002 ± 0.001	0.37 ± 0.27	2.76 ± 1.68	0 ± 0	2 ± 2.8
17	1	0.05	1	Nd	< 0.2	1	0.001	52.8	1.27	5	1
18a	5	1.41 ± 3.06	0.8 ± 1.8	1.6 ± 1.5	0 ± 0	0.2 ± 0.4	0.4 ± 0.9	0.47 ± 0.10	1.08 ± 0.14	4.8 ± 3.6	0.8 ± 1.1
18b	1	0.047	5	Nd	< 0.2	< 0.2	0.002	0.5	1.04	12	2
19	2	12.82 ± 18.07	2.5 ± 3.5	0.5 ± 0.7	0 ± 0	< 0.2	0.002 ± 0.001	0.49 ± 0.08	8.16 ± 1.15	0 ± 0	12.4 ± 15.1
20	1	0.04	5	0	< 0.2	< 0.2	0.002	0.13	0.09	0.002	1
21	3	0.04 ± 0	3 ± 2.6	0.7 ± 1.1	0 ± 0	0 ± 0	0.002 ± 0.002	0.53 ± 0.10	8.72 ± 1.26	0 ± 0	20.6 ± 4.0
22	4	0.04 ± 0	2.8 ± 3.2	0.5 ± 1	0 ± 0	0.3 ± 0.5	1.3 ± 0.5	0.63 ± 0.12	6.38 ± 0.81	0 ± 0	0.5 ± 1.0
23	3	0.05 ± 0	0 ± 0	1 ± 1	0 ± 0	0.7 ± 0.5	0.7 ± 0.6	3.11 ± 1.54	1.62 ± 0.45	0 ± 0	1.7 ± 2.1
24	2	5.67 ± 7.96	0 ± 0	2.5 ± 0.7	0 ± 0	0.5 ± 0.7	0.5 ± 0.7	0.57 ± 0.01	2.27 ± 0.01	0 ± 0	0 ± 0
25	5	10.52 ± 23.41	2 ± 2.3	0.8 ± 1.0	0.2 ± 0.4	0.6 ± 0.9	0.6 ± 0.5	0.37 ± 0.08	4.31 ± 0.61	0 ± 0	5.8 ± 3.8

on aquifers. The use of drinking water action levels to judge the adequacy of mineral waters for human consumption have been discussed in the past (Misund et al., 1999) and we recommend that the present use of drinking water standards for spring-type bottled waters be reviewed. Total organic carbon levels were high in some samples, especially the spring waters. The presence of natural organic matter (NOM), trihalomethanes (THMs) and other volatile organic compounds (VOCs) raises the level of TOC in drinking water. It may be necessary to remove organics in mineral and spring waters before bottling. Contamination of bottled water during production processes should also be minimized to avoid exposure of humans to the toxic effects of chemicals.

There is a considerable variation in the quality of source water for bottled water production within each geographical area and wider differences do exist from country to country. Also, there is a variation in the quality of personnel and treatment technologies employed by various bottled water manufacturers. However, the need for more stringent uniform drinking water quality standards for all countries is becoming increasingly imperative, but its implementation may be difficult because of cost problems. In addition, action levels and toxicological effects of ingestion of certain elements like thorium are currently lacking.

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Table 6 (*Continued*)

Brand	*n*	Na (mg/l)	Zn (μg/l)	Th (μg/l)	U (μg/l)	Hg (μg/l)	Sulfate (mg/l)	Chloride (mg/l)	Total Alkalinity (mg/l)	Nitrate + Nitrite (mg/l)
1	1	23	27	Nd	Nd	14	79.69	49.77	155.88	1.1
2	7	4.28 ± 8.62	0.9 ± 0.7	2.3 ± 2.9	0.7 ± 0.8	3 ± 5.1	0.24 ± 0.21	3.9 ± 1.16	4.24 ± 1.76	0.19 ± 0.21
3	1	1.61	0.01	Nd	Nd	0.01	5.84	5.7	139.75	0.8
4	1	8.92	0.011	Nd	4	Nd	0	27.14	0	6.4
5	2	2.57 ± 0.14	5.5 ± 2.1	0.5 ± 0.7	4.5 ± 0.7	33 ± 14.1	6.89 ± 0.644	6.65 ± 0.0	123.63 ± 13.68	2.1 ± 0.28
6	4	1.21 ± 0.95	1.3 ± 0.5	4.8	1.5 ± 0.6	3 ± 2.9	2.58 ± 4.57	6.87 ± 5.06	28.78 ± 43.9	0.85 ± 1.17
7	3	23.52 ± 18.23	8 ± 8.7	0 ± 0	0.7 ± 1.1	12 ± 16.5	20.40 ± 7.24	48.76 ± 35.27	86.72 ± 44.39	1.83 ± 0.21
8	11	12.89 ± 31.21	3.8 ± 10.7	3.0 ± 6.5	2.5 ± 6.5	20 ± 29.8	14.29 ± 0.99	8.38 ± 0.68	7.50 ± 2.32	0.12 ± 0.13
9	1	6.38	8	Nd	4	51	2.49	18	225.75	1.1
10	6	5.33 ± 0.45	2.2 ± 1.0	2.2 ± 3.0	2.3 ± 2.7	24.7 ± 28	14.56 ± 1.53	4.70 ± 0.92	30.21 ± 0.57	0.3 ± 0.2
11	1	2.06	3	2	1	75	12.94	6.13	44.79	1.8
12	1	5.98	15	5	1	Nd	5.63	7.17	35.83	0.8
13	2	6.79 ± 5.96	4.5 ± 4.9	2 ± 2.8	4 ± 4.2	3.5 ± 4.9	6.39 ± 6.20	10.09 ± 9.78	64.73 ± 27.69	1.55 ± 1.63
14	1	2.97	6	11	18	Nd	15.69	23.75	129	1.7
15	2	92.91 ± 128.82	11 ± 11.3	2 ± 2.8	0 ± 0	0 ± 0	7.98 ± 2.52	10.38 ± 9.51	51.6 ± 42.57	8.3 ± 11.6
16	2	11.4 ± 1.84	4.5 ± 0.7	16 ± 22.6	8 ± 1.4	10 ± 14	41.93 ± 5.49	28.03 ± 0.67	243.74 ± 138.22	6.4 ± 0.85
17	1	1.82	8	3	1	1	1.59	16	96.96	1.1
18a	5	26.75 ± 50.45	2.4 ± 2.7	1 ± 1.4	1.2 ± 0.8	7.4 ± 16.5	7.35 ± 0.67	7.72 ± 2.03	28.51 ± 9.19	0.66 ± 0.29
18b	1	3.41	4	28	12	Nd	5.57	7.6	25.3	0.5
19	2	6.17 ± 0.28	3.5 ± 0.7	0 ± 0	1 ± 1.4	13 ± 9.9	9.20 ± 0.34	15.68 ± 0.67	55.9 ± 30.41	10.6 ± 0.42
20	1	2.64	< 0.1	4	2	79	2.64	5.55	2.69	0.1
21	3	6.44 ± 0.62	3 ± 0	0.7 ± 1.1	5.3 ± 3.2	12.7 ± 11	9.42 ± 0.33	26.05 ± 16.73	87.43 ± 17.38	14.6 ± 5.59
22	4	2.17 ± 0.56	4 ± 1.8	2.3 ± 2.6	1.3 ± 1.0	6 ± 4.7	10.24 ± 0.26	14.66 ± 5.02	110.84 ± 31.88	0.2 ± 0.22
23	3	8.18 ± 0.76	3 ± 1	7 ± 7	4.7 ± 8.1	7.7 ± 13.3	1.73 ± 1.17	6.71 ± 0.91	34.68 ± 1.75	1.4 ± 0.17
24	2	143.8 ± 187.0	2 ± 0	0 ± 0	2.5 ± 3.5	0 ± 0	9.89 ± 0.21	17.81 ± 0.0	36.55 ± 3.04	2.6 ± 0.42
25	5	6.69 ± 0.43	5.4 ± 2.6	6.6 ± 12.1	5.4 ± 5.9	16.6 ± 22	14.32 ± 0.54	15.13 ± 1.24	108.84 ± 51.22	5.46 ± 1.31

n: number of samples analyzed; na: not analyzed; nd: not detected.

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