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Bottled water selection and health considerations from multi-element analysis of products sold in New York state

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ABSTRACT

Nineteen bottled water products were purchased from stores in Potsdam and Wappingers Falls, New York and analyzed for 71 inorganic elements by inductively coupled plasma – mass spectrometry (ICP-MS). The wide range in elemental concentrations observed suggests considerable variation in source water composition, processing, and treatment. Comparison with samples from a typical small municipal water system (Potsdam, New York) was made to evaluate the differences between bottled and municipal water and in many cases little difference is apparent. With the exception of one sample of tonic water and one mineral water, all bottled waters tested meet United States Environmental Protection Agency (USEPA) primary standards for drinking water supplies. Ingestion of some of the waters could provide significant percentages of the reference daily intakes (RDI) of key trace elements. Knowledge of the inorganic chemistry of bottled water can help consumers select the brands best suited to their individual health needs or preferences.

Key words | bottled water, drinking water, multi-element analyses

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INTRODUCTION

While problems associated with bacteriological and organic contaminants often come to the forefront of drinking water concerns, a growing awareness of the potentially negative health consequences of certain inorganic constituents is also emerging. Recent studies related to ingestion of metals and metalloids in drinking water have led many to begin to question the safety of their own water supply in terms of its metals content. For example, research on arsenic in water supplies has publicized health issues related to natural inorganic contaminants in water (e.g. Ayotte *et al.* 2003). Nonetheless, most real estate transactions still require little more than a bacteriological test of an existing private water supply. A goal of this study was to determine the variation in the inorganic constituents of various brands of bottled water sold in New York State and whether or not they meet USEPA drinking water standards (e.g. Ikem *et al.* 2002).

Access to abundant, clean water is among the most essential needs for life. In developed countries and urban areas human needs are largely met by municipal systems designed to provide potable water free of pathogens, bacteria, and organic and inorganic contaminants. However, pollutants introduced by anthropogenic activities, disinfection, and/or natural circumstances can impact both municipal and private water supplies. For a variety of reasons, including fear of contamination and personal perceptions, many consumers now choose to drink bottled water (Garzon & Eisenberg 1998), at prices far in excess of water provided by municipal systems. While the purchase of bottled water products may allay fears, their source and chemical characteristics vary widely (Misund *et al.* 1999) and they are not necessarily better and/or different than water available from municipal systems. A second goal of this study was to investigate if consumption of bottled water in preference to water from a typical municipal water supply is justified in terms of inorganic contaminant concentrations and health considerations (Garzon & Eisenberg 1998).

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The average adult consumes the equivalent of approximately four litres of water a day, thus drinking water is a potential exposure pathway for a variety of inorganic contaminants. Mineralized water can also provide a considerable amount of required nutrients such as calcium and magnesium, along with numerous other elements, generally in trace concentrations, whose effects on human health are inadequately understood or unknown. It is also widely understood that drinking large quantities of distilled or deionized water is potentially harmful in certain circumstances if critical nutrients are lost and not replaced. Ideally, consumers of bottled water should use information on inorganic chemistry in their selection of bottled water products. A third goal of this study was to provide a guide to the brands tested based on both positive and negative characteristics, recognizing that the appropriate selection of a bottled water product may vary based on personal health circumstances.

MATERIALS AND METHODS

Nineteen different brands of commercial bottled water, including tonic water, mineral water, and distilled water, were purchased at various stores in Potsdam and Wappingers Falls, New York and represent the range of "water" products sold for personal consumption. Samples of Potsdam municipal water were collected from several water fountains on the State University of New York's Potsdam campus. A small aliquot of water was poured into pre-cleaned glassware to measure physical parameters. A Horiba model #U10 Multimeter was used for measurements of pH, salinity, and conductivity. Dissolved oxygen was measured using an YSI model 55 probe. Samples were then poured from the original commercial container (glass or plastic) into 125 ml sterile bottles (Wheaton Cleanpak® Precleaned Sample Containers). Samples were immediately shipped for ICP-MS (Inductively Coupled Plasma Mass Spectrometry) analysis to ACME Analytical Laboratories LTD in Vancouver, British Columbia. Each sample was tested for 71 inorganic elements. Major elements (K, Na, Ca, Mg, Fe, and Si) had detection limits of 5–20 μg/L, depending on the element, while trace elements detection limits were generally substantially lower (ng/L). Chlorine and sulfur had detection limits of 1 mg/L (see online supplementary data file available at: http://www.iwaponline.com/jwh/006/0064.xls).

Several quality assurance steps were taken to insure the integrity of the data obtained. Bottled water samples were spiked with 5 μg of 1,000 μg/ml beryllium standard in 2% HNO_3 for use as an internal standard and to check recovery. Samples of municipal water were not spiked with beryllium. One sample container was shipped empty and filled at the laboratory with reagent grade water. This sample served as a method blank to monitor the cleanliness of the laboratory environmental and various sample processing procedures. Three sets of duplicate samples were analyzed to check precision and a standard wastewater (B2) was run with the samples to determine the accuracy of the analyses.

RESULTS AND DISCUSSION

Quality control and generalized chemical parameters

Based on the quality control samples analyzed the concentrations measured in this study were both accurate and precise. Beryllium recoveries from our samples averaged 87% of what was added (41.6 μg/L). In the method blank, only Ba, Ni, S, Sr, Si, and Zn were detected at concentrations slightly above their respective detection limits, and except for Ni, they were generally $\sim 100\times$ less than that found in most water samples. The elemental composition of duplicate samples was nearly identical and the concentrations measured were in excellent agreement with those reported for the certified wastewater standard. The concentrations of detected elements and detection limits (<) are shown in the supplementary data and Table 1. Results from the Potsdam municipal supply ($n = 5$) are shown for five locations on campus (Figure 1).

The inorganic chemistry of bottled water samples varied widely with significant differences apparent on Piper, Stiff, and Schoeller diagrams related to the relative proportions of the major constituents and the amount of total dissolved solids (TDS). Figure 1 displays these differences on a ternary diagram showing the normalized proportions of calcium, magnesium, and sodium (Figure 1(a)) and calcium, chlorine, and sulfur (Figure 1(b)). Most of the waters have calcium as the dominant cation, although a considerable range is apparent from 2–91% (Ca), 5–70% (Na), and 3–50% (Mg). Chlorine and sulfur also vary widely with several samples having non-detectable concentrations of one or both. Select parameters of aesthetic concern (pH, TDS, Cl, Na, and S, heavy metals and metalloids (As, Cd, Cr, Cu, Hg, Ni, Pb, V), nutrients (Ca, Fe, K, Mg, Zn) and radionuclides (Th, U) are summarized in Table 1, while the supplementary data gives the entire data set.

Individual elements range over several orders of magnitude, largely as a function of pH, which ranged considerably (2.5–7.73). Tonic water, seltzer water, and highly mineralized waters had lower pHs ranging from ~2.5–5.8, whereas other samples ranged from pH 6.0–7.73 (Table 1). Five samples from the Potsdam municipal system varied little in pH and ranged from 6.68–6.73.

The samples appear to be derived from different types of water including: mineralized springs (high Na, Cl, Ca, Mg, low pH, highest TDS), hard water from carbonate aquifers (high Ca, slightly alkaline pH, high TDS), and those which have been distilled or treated to remove dissolved constituents (low pH, low TDS). Gerosteiner mineral water had a TDS of 528 mg/L and hence is highly mineralized, whereas the brands Aquafina (5 mg/L) and Great Value distilled water (9 mg/L) had few dissolved solids.

Five samples of Potsdam municipal water collected on campus show remarkable consistency in most of their major constituents, however, the taste, smell, turbidity, color, and trace metal concentrations of the water can differ across campus. One sample had high copper concentrations (234 μg/L), likely related to older (1960's vintage) plumbing. Zinc concentrations were also high but variable. This, and the local differences noted in water quality, is probably due to the age and condition of plumbing that the water travels through and residence time in the water fountains prior to use. Samples from campus have between 10–12 ppm Cl and 9–11 ppm S. This is in agreement with antidotal reports that the water, at times, tastes chlorinated and gives off a slight sulfur smell impacting its aesthetic qualities.

What is in bottled water and where did it come from?

Bottled water can be derived directly from aquifers, springs, highly mineralized springs, reservoirs, and/or other surface waters (United States Environmental Protection Agency 2005). Somewhat surprisingly and in contrast to what might be inferred from advertisements, from 25–40% of bottled water (Olson 1999) is filled directly from municipal systems, likely at immense profits. In many instances the water chemistry has been modified by a number of different processes prior to bottling (e.g. filtration, distillation, reverse osmosis, etc). It is also possible that certain elements (e.g. calcium, sodium, chlorine) are introduced during preparation, handling, disinfection, and/or even from the containers themselves, as has been found for antimony (Shotyk & Krachler 2007). But in general, the inorganic chemistry of water is strongly influenced by the geologic materials it is derived from. Even rainwater contains small concentrations of dissolved inorganic elements, and energy must be expended to remove them from more concentrated ground and surface waters to provide distilled or "purified" water.

The bottled waters in this study had between 11–50 detectable elements out of the 71 analyzed (see supplementary data). Virtually every sample contained detectable quantities of Ca, Na, Rb, Si, and Sr. More than half also contained Al, Ba, Br, Cl, Cu, K, Li, Mg, Mo, S, and Sb. Certain elements, generally relatively rare and highly insoluble (Bi, Dy, Eu, Ho, Lu, Os, Pb, Pt, Sm, Ta, Tb, and Tm), were not detected in any of the bottled water samples. Many of the trace elements (Ag, Au, Ce) were found in only a single sample with low pH. By far, Ca, Cl, K, Mg, Na, S, and Si dominated the dissolved inorganic portion of the bottled waters studied. However, the proportion of the major cations varies considerably (Figure 1), attesting to the wide variety of waters sampled.

Water from the municipal water supply in Potsdam, New York contained 22–26 detectable elements and was dominated by the same elements as in the bottled water samples. In contrast to most of the bottled waters sampled, the Potsdam municipal supply is dominated by Na (Figure 1), a function of geology of the Raquette River drainage basin. The Raquette River drains the central portion of the Adirondack Mountains underlain by crystalline bedrock with only minor amounts of carbonate bearing rocks (marble). The bedrock there plays an important role in the acidification of Adirondacks lakes and rivers because few ions capable of neutralizing acid species are available and hence Ca and Mg concentrations are proportionally low.

Table 1 | Concentrations of select inorganic parameters found in bottled water and Potsdam municipal water collected from the SUNY campus

	pH/Salinity/Taste/Odor					**Metals**								**Nutrients**					**Radioactivity**	
		TDS	**Cl**	**Na**	**S**	**As**	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**V**	**Ca**	**Fe**	**K**	**Mg**	**Zn**	**Th**	**U**
Brand/water	**pH**	**ppm**	**ppm**	**ppm**	**ppm**	**ppb**	**ppb**	**ppb**	**ppb**	**ppb**	**ppb**	**ppb**	**ppb**	**ppm**	**ppb**	**ppb**	**ppm**	**ppb**	**ppb**	**ppb**
Evian	7.33	137	7	9	6	0.8	< 0.05	14.5	< 0.1	0.2	< 0.2	< 0.1	0.2	58	< 10	1017	33	< 0.5	0.06	1.84
Polar tonic	*2.47*	107	28	19	20	4.2	1.53	374.5	0.4	0.1	12.3	< 0.1	1.4	39	195	1895	0.87	1	0.07	0.05
Hannaford spring	7.01	54	18	10	4	< 0.5	< 0.05	1.8	0.7	< 0.1	< 0.2	< 0.1	0.2	15	< 10	662	3	< 0.5	< 0.05	< 0.02
SUNY-Potsdam	7.08	80	5	3	5	< 0.5	< 0.05	2.5	1.1	0.1	< 0.2	< 0.1	< 0.2	33	< 10	640	3	< 0.5	< 0.05	0.03
Hannaford seltzer	*4.17*	94	28	16	32	< 0.5	< 0.05	0.6	0.1	0.1	< 0.2	< 0.1	3	44	13	1347	1	< 0.5	< 0.05	< 0.02
Poland spring	*6.49*	24	5	4	2	< 0.5	< 0.05	0.7	< 0.1	< 0.1	< 0.2	< 0.1	< 0.2	8	< 10	522	1	< 0.5	< 0.05	< 0.02
Great value drink	*6.06*	15	< 1	2	< 1	< 0.5	< 0.05	< 0.5	50.6	< 0.1	1.1	3.2	< 0.2	0.06	< 10	< 50	< 0.05	64	< 0.05	< 0.02
Great value spring	7.65	194	62	29	13	< 0.5	< 0.05	10.3	0.2	0.1	< 0.2	< 0.1	< 0.2	79	13	2120	15	< 0.5	< 0.05	0.13
Great value distill.	6.65	9	< 1	2	2	< 0.5	< 0.05	0.7	< 0.1	< 0.1	0.6	< 0.1	< 0.2	0.08	10	< 50	< 0.05	< 0.5	< 0.05	< 0.02
Dasani	*6.00*	24	6	3	7	< 0.5	< 0.05	0.7	< 0.1	< 0.1	0.7	< 0.1	< 0.2	0.08	< 10	3200	4	6.1	< 0.05	< 0.02
Kinney drugs	7.73	142	36	18	8	< 0.5	< 0.05	9.8	0.2	0.1	< 0.2	< 0.1	< 0.2	65	< 10	2412	15	< 0.5	< 0.05	0.11
Aquafina	*6.09*	5	< 1	2	2	< 0.5	< 0.05	0.7	< 0.1	< 0.1	0.8	0.1	< 0.2	0.14	< 10	< 50	< 0.05	0.5	< 0.05	< 0.02
Deja blue	*5.66*	23	5	6	3	< 0.5	< 0.05	0.5	0.3	< 0.1	< 0.2	< 0.1	< 0.2	3	< 10	429	0.81	0.5	< 0.05	< 0.02
Iroquois spring	7.18	93	24	10	7	< 0.5	< 0.05	5.5	0.5	< 0.1	< 0.2	< 0.1	< 0.2	41	< 10	1351	11	< 0.5	< 0.05	0.26
Fiji spring	7.51	114	9	19	< 1	1.2	< 0.05	8	< 0.1	0.1	< 0.2	< 0.1	58.1	19	< 10	4468	15	< 0.5	< 0.05	0.02
Pocono spring	*5.87*	17	< 1	0.4	< 1	< 0.5	< 0.05	< 0.5	< 0.1	< 0.1	1.6	< 0.1	< 0.2	1	< 10	226	0.9	6	< 0.05	< 0.02
Kynica mineral	*4.80*	95	1	4	11	< 0.5	< 0.05	19	0.1	0.1	< 0.2	< 0.1	< 0.2	48	< 10	720	14	4.8	< 0.05	0.13
Gerosteiner mineral	*5.79*	*528*	39	136	21	0.9	< 0.05	87.5	1.5	0.3	12.8	< 0.1	0.5	172	86	17032	108	3.9	< 0.05	0.78
Peirrier mineral	*5.22*	203	17	12	10	0.8	< 0.05	102.1	0.3	< 0.1	4.9	< 0.1	< 0.2	156	*300*	1078	6	0.8	< 0.05	6.49
Poland spring dup.	7.42	27	5	5	3	< 0.5	< 0.05	5	< 0.1	< 0.1	< 0.2	< 0.1	< 0.2	9	< 10	656	1	< 0.5	< 0.05	< 0.02
Fiji spring dup	6.73	124	10	21	< 1	1.2	< 0.05	8.1	< 0.1	0.1	< 0.2	< 0.1	60.5	19	< 10	4691	15	< 0.5	< 0.05	0.02
Potsdam #1	6.73	53	10	20	11	< 0.5	0.08	0.8	233.9	< 0.1	0.2	1.4	< 0.2	6	17	387	1.6	80	< 0.05	< 0.02
Potsdam #2	6.70	54	11	20	11	< 0.5	< 0.05	1.2	116.4	< 0.1	0.8	1.2	< 0.2	7	19	402	1.6	172	< 0.05	< 0.02
Potsdam #3	6.72	54	11	19	11	< 0.5	< 0.05	1.4	21.4	< 0.1	2.2	0.2	< 0.2	8	11	401	1.8	194	< 0.05	< 0.02
Potsdam #4	6.70	57	12	19	11	< 0.5	< 0.05	0.8	13.6	< 0.1	< 0.2	0.3	< 0.2	9	13	658	2.5	29	< 0.05	< 0.02
Potsdam #5	6.69	50	10	19	10	0.5	< 0.05	1.1	22.7	< 0.1	0.5	< 0.1	0.2	7	< 10	413	1.6	41	< 0.05	< 0.02
Potsdam #6	6.68	51	10	20	9	0.6	< 0.05	0.7	20.4	< 0.1	< 0.2	< 0.1	0.3	7	< 10	407	1.7	21	< 0.05	< 0.02
Potsdam #6 dup.	6.68	42	10	20	9	0.6	< 0.05	1.2	18.7	< 0.1	< 0.2	< 0.1	0.3	7	< 10	418	1.6	17	< 0.05	< 0.02
Potsdam avg.	6.70	52	11	20	10	0.57	0.08	1.0	63.9	< 0.1	0.9	0.8	0.27	7	15	440	2	79	< 0.05	< 0.02
USEPA primary MCLs						10	5	100	1300	2		15								30
USEPA secondary MCLs	*6.5–8.5*	*500*	*250*		*250*				*1000*						*300*			*5000*		

Chlorine secondary maximum contaminant level (MCL) as chloride; sulfur MCL as sulfate.

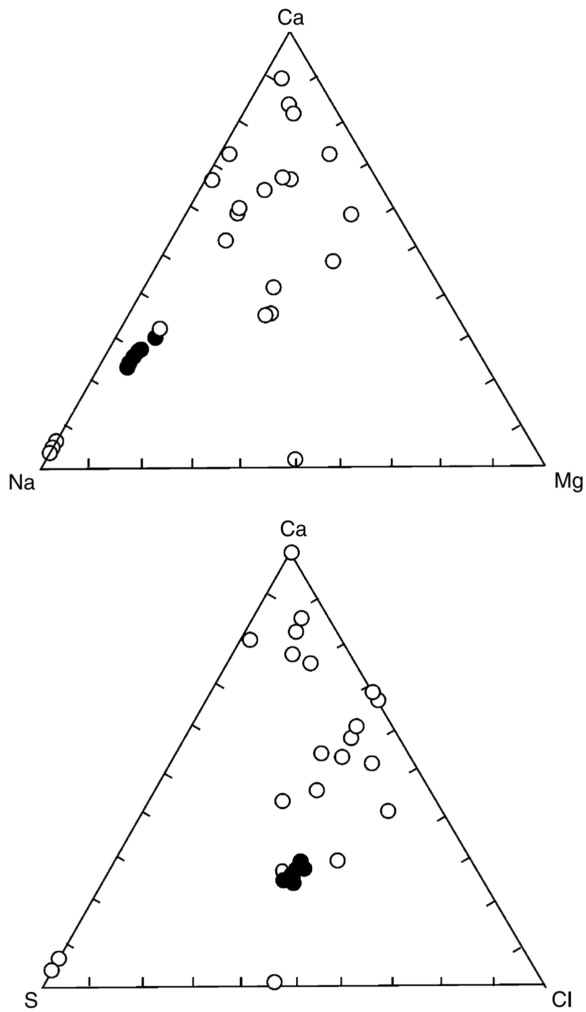

Figure 1 | Ternary plots (Ca-Mg and S-Ca-Cl) displaying normalized proportions of major elements in bottled water products (open circles) and samples of the Potsdam municipal water supply (filled circles).

Do the waters sampled meet USEPA drinking water standards?

The USEPA has both primary and secondary standards for contaminants in public water supplies (United States Environmental Protection Agency 2008). Only constituents which have a direct relevance to human health have primary standards enforced as maximum contaminant levels (MCLs). Secondary standards, based on aesthetic concerns, are non-enforceable. With two exceptions, all of the samples meet the primary maximum contaminant levels (MCLs) set by the EPA (Table 1). A sample of Peirrier Mineral water slightly exceeded the 0.100 mg/L USEPA MCL for chromium at 0.102 mg/L. Polar tonic water contained the highest concentrations of many other elements including As, Cr, Ni, and Th compared to the other bottled water types and exceeded the chromium MCL by nearly four times (0.375 mg/L). According to the Polar Company's web-site (Polar Company, website), the ingredients of Tonic water are: Carbonated water, high fructose corn syrup, citric acid, natural and artificial colors, and quinine. Quinine is a bitter crystalline alkaloid, made of $C_{20}H_{24}N_2O_2$. It is made of cinchona bark, and often used for medicinal purposes such as easing muscle tension. It is likely that many of the metals are derived from the ingredients of the tonic water or as an indirect consequence of its low pH (2.47), a reflection of its carbonation.

A number of water samples exceeded secondary MCLs for pH because of their acidity (<6.5). These include low pH seltzer and tonic waters, as well as, a number of spring water samples. Gerosteiner Mineral water has a TDS concentration of 539 mg/L, just above the secondary standard of 500 mg/L. Peirrier water had 0.300 mg/L iron which is at, but does not exceed the secondary MCL. Secondary standards are non-enforceable.

In all, two exceedences of primary (chromium) and twelve of secondary (11 – pH, 1 – TDS) MCLs were noted in this study. In general, the waters analyzed were fit for drinking purposes in contrast to an earlier study of bottled waters in Atlanta. Ikem *et al.* (2002) found that about 20% of the bottled waters they analyzed contained arsenic above 10 μg/L and several waters exceeded USEPA MCLs for mercury and uranium.

Is the consumption of bottled water preferable to municipal water in terms of its inorganic chemistry?

Potsdam, New York draws its potable water from the Raquette River which drains a sparsely populated and forested area of the Adirondack Mountains. In general, the river water is of high quality but dark in appearance, because of natural tannin and other dissolved organic compounds. Particulates and dissolved organic compounds are removed from river water using alum as a flocculent and treated with chlorine prior to distribution. Sampling of water from the municipal facility over the past several years has shown that the water chemistry is fairly consistent (Figure 1) and of good quality (Chiarenzelli *et al.* 2007).

The data table and summary provided (see supplementary data and Table 1), suggests that the water provided by the Potsdam water treatment plant has both desirable and non-desirable characteristics. Positive attributes include fairly low TDS, low chlorine, non-detectable mercury, and the lack of radioactive elements. On the negative side, it has fairly high sodium concentrations and detectable concentrations of most heavy metals including chromium, copper, and occasionally lead. An important question is how much of the metals found are actually from the municipal source and how much is introduced by the antiquated plumbing system where sampled? Previous analyses (Chiarenzelli *et al.* 2007) from other areas in town receiving municipal water suggest that much of the metals are derived from the plumbing on campus. In particular, older water fountains, like those at our sample sites on campus, have the capacity to store water which may be in contact with metallic parts for extended durations.

The benefits of selecting a particular bottled water source in Potsdam, New York depend entirely on the brand selected and the reason for selection. The Potsdam municipal water source compares favorably with many of them. From a public health perspective, municipal water sources are monitored frequently and, barring problems, provide a consistent and safe water supply. On the other hand the natural characteristics of the water, possible seasonal and hydrologic variations, chlorination and disinfection byproducts, taste, and odor may make public water supplies aesthetically less desirable to some people. In contrast, relatively little is known about the source(s), characteristics, and variability of bottled water products.

What about private wells? It is very difficult to generalize based on a number of factors which can influence the quality and chemistry of water at the wellhead. However, in rural areas of northern New York water quality is general excellent. A recent study of private wells on the Mohawk Reservation approximately 25 miles north of Potsdam found that water quality, based on inorganic parameters, was variable but generally good (Chiarenzelli *et al.* 2007). Very few samples exceeded the USEPA's primary MCLs. A larger county-wide study (St. Lawrence County, NY) is underway and suggests that groundwater quality is generally excellent, but highly variable, based on local geology.

What criteria should be considered when selecting a bottled water product?

Obvious factors to consider when selecting a bottled water product for personal consumption include cost, source (which can often be incorrectly inferred from advertising, packing, and brand name), taste, odor, clarity, salinity, and other aesthetic factors. A less obvious factor which cannot often be readily sensed is the chemistry of the water. In this study all drinking water products randomly selected and analyzed at a single point in time, with the exception of tonic water and one mineral water (Table 2), met USEPA primary maximum contaminant levels for heavy metals and radionuclides (c.f. Misund *et al.* 1999; Ikem *et al.* 2002). Only one bottled water product exceeded recommended guidelines for total dissolved solids. Since the waters sampled by this survey were selected from the grocery isle at random, one might infer that there is relatively little concern in regards to heavy metals and radionuclides in the water

Table 2 | Percentage of Reference Daily Intakes (2000 calorie/day diet; United States Food and Drug Administration) based on ingestion of two litres of the water samples analyzed

Element	RDI	Gerosteiner mineral water	Potsdam municipal water	Aquafina
Calcium	1,000 mg	34.4%	1.4%	< 0.1%
Chlorine	3,400 mg	2.3	0.6	< 0.1
Chromium	120 mcg	145.8	1.7	1.1
Copper	2 mg	0.2	3.2	< 0.1
Iron	18 mg	1.0	0.2	< 0.1
Magnesium	400 mg	54.0	0.8	< 0.1
Manganese	2 mg	15.0	0.2	< 0.1
Molybdenum	75 mcg	0.53	0.3	< 0.1
Phosphorous	1,000 mg	< 0.1	< 0.1	< 0.1
Potassium	3,500 mg	1.0	< 0.1	< 0.1
Selenium	70 mcg	2.6	< 0.1	< 0.1
Sodium	2,400 mg	11.3	1.6	0.2
Zinc	15 mg	< 0.1	1.1	< 0.1

RDI – recommended daily intake.

products sold commercially. This may not be an entirely accurate assessment, particularly for highly mineralized waters (e.g. Misund *et al.* 1999; Ikem *et al.* 2002). Nonetheless many brands sold in New York and analyzed in this study had non-detectable or low concentrations of most inorganic contaminants.

Concerns related to taste, odor, and other aesthetic factors are a function of personal preferences. Most people find the taste of chlorine and sulfur offensive and thus might choose to avoid brands with elevated chlorine and sulfur contents. Maximum chlorine concentrations of 62 mg/L were found in one brand while as much as 32 mg/L of sulfur was found in another. Several brands had non-detectable concentrations of chlorine and sulfur (detection limit of 1 mg/L for both) and may appeal to those with low tolerance for taste and smell or health concerns related to the consumption of trihalomethanes and other chlorination/disinfection byproducts.

Another aspect of water quality which receives relatively little discussion is the nutritional value of various waters, perhaps because those with appropriate diets derive the vast majority of their nutrients from solid food. Numerous elements serve as nutrients, and in Table 2 we evaluate elements for which Reference Daily Intakes (RDIs replaces RDAs) are available (United States Food and Drug Administration 2003). In certain instances, waters which lack nutrients can be detrimental to good health by facilitating loss of critical nutrients eventually resulting in chemical imbalances or deficiencies (Garzon & Eisenberg 1998). Distilled and treated waters have low concentrations of most, if not all nutrients, and generally are not recommended for personal consumption. Several brands studied have very low total dissolved solids concentrations and hence likely have undergone treatment (e.g. distillation, reverse osmosis, etc) to remove inorganic components. One brand investigated was sold as distilled, often considered by some as equivalent to purified, although improper handling or containers could add inorganic or organic contaminants or bacteria to distilled water.

Calcium and magnesium are essential nutrients and are found in abundance in hard waters, but at varying ratios to one another. Potassium is found in most of the water samples, ranging from non-detectable to over 17 mg/L. Iron is nearly insoluble in oxidized waters at near neutral pH and hence is generally only found in tonic, seltzer, and highly mineralized, low pH waters. Zinc is found above detection limits in about half the samples analyzed, but is generally at low concentrations. The more mineralized waters tend to contain significant concentrations of nutrients. For example, Gerosteiner Mineral water contains Ca (172 mg/L), Fe (86 μg/L), K (17 mg/L), Mg (108 mg/L), and Zn (3.9 μg/L).

People with specific nutritional or health concerns and/or susceptible populations would likely benefit by selecting waters with compatible inorganic parameters. For example, those susceptible to osteoporosis should refrain from waters with low TDS and select waters with elevated calcium and magnesium concentrations. Conversely, those with problems related to kidney stones may benefit from avoiding hard or mineralized waters. Further, those suffering from hypertension should monitor their sodium intake and avoid foods and waters with high sodium content. This is generally not of concern in most bottled waters or municipal systems where sodium concentrations are low, but may be of concern in highly mineralized waters (United States Environmental Protection Agency 2007).

In Table 1 we calculated the amount of each nutrient for which Reference Daily Intakes (RDIs) are available for water with greatest (Gerosteiner Mineral water – 539 mg/L), and least (Aquafina – 4 mg/L) TDS concentrations. For comparison, values for the Potsdam municipal water supply were also calculated (TDS – 50.7–57.7 mg/L). Note that the concentration of dissolved inorganic constituents varies over three orders of magnitude in this small sampling of available commercial waters. Based on Table 2, using a consumption of two litres of water per day, it appears that most drinking waters do not serve as a substantial source of many nutrients, although considerable variation occurs. Of particular interest we found that two litres per day of Gerosteiner Mineral water was found to provide 34% of calcium, 54% of magnesium, and 146% of chromium RDIs. Aquafina provides relatively little except a minor percentage of the RDIs for chromium and sodium. The Potsdam municipal water supply provides a small percentage of the RDI of most elements. Potsdam's water source, the Raquette River, drains the relatively insoluble crystalline rocks of the Adirondack Mountains and has little dissolved inorganic matter. Municipal water supplies with greater TDS concentrations than Potsdam's would be expected to provide a proportionally greater amount of many elements. Interestingly and somewhat ironically, the antiquated plumbing in SUNY Potsdam's buildings could provide a small percentage of RDIs for the trace elements chromium (1.7%), copper (3.2%) and zinc (1.1%), leaching from the plumbing. A major question is whether the elements in water are in a form which allows ready uptake by the digestive system.

CONCLUSIONS

The data presented in this study suggest that the commercially available bottled waters sold in New York State and analyzed in this study, have inorganic concentrations well within the primary maximum contaminant levels set by the USEPA; speciality waters (seltzer, mineralized, etc) with lower pH tend to violate the MCL for acidity. The waters analyzed have different inorganic compositions and major element ratios based on their source and treatment(s) and their total dissolved solids vary by over three orders of magnitude. Further, the municipal water source of Potsdam, New York, provides water that is of a quality equal to, or exceeding, many of the bottled waters analyzed based on inorganic parameters. Select inorganic parameters have been discussed as examples to serve as a guide to consumers with particular health needs, enhanced susceptibility, and/or preferences in drinking water selection.

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