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ORIGINAL ARTICLE

Chemical Evaluation of Commercial Bottled Drinking Water from Egypt

Mahmoud A. Saleh[1], Emmanuel Ewane, Joseph Jones, and Bobby L. Wilson

Department of Chemistry, Environmental Chemistry and Toxicology Laboratory, Texas Southern University,
3100 Cleburne Ave., Houston, TX 77004, U.S.A.

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Inorganic constituents and trihalomethanes were analyzed in five major brands of commercial bottled water currently used by many Egyptians and tourists visiting Egypt. The inorganic analysis included determination of both anion and cation species. Trihalomethanes analysis included the determination of chloroform, bromodichloromethane and dibromochloromethane. For the purpose of comparison, selected samples of tap water and rain water from Cairo and Giza were also analyzed. Inductively coupled plasma mass spectrometry (ICP/MS) was used for the analysis of elements including heavy metals. Ion chromatography (IC) was used for the analysis of anions. Ion selective electrodes (ISE) were used for measuring physical constants and for the analysis of nitrite, cyanide and sulphide ions, and ammonia. Gas chromatography and gas chromatography/mass spectrometry (GC/MS) were used for the analysis of trihalomethanes. All water samples were within the acceptable levels of the World Health Organization (WHO) guidelines and were lower than maximum contaminant levels (MCL) established by the United States Environmental Protection Agency (USEPA). Tap water from both Cairo and Giza was of a higher quality than any of the bottled water with regard to the analyzed chemical constituents. Out of the five brands of bottled water only Mineral® brand had a concentration level approaching the maximum allowed concentration for most of the chemical constituents, and it also contained the highest total dissolved solids. Trihalomethanes were found in all of the tap water but at much lower levels in Baraka® and Siwa® bottled water. Charcoal filters were effective in reducing the trihalomethanes concentration but showed no significant changes in other constituents.

Key Words: drinking water; bottled water; Egypt; pollutants; ion chromatography; ICP/MS.

INTRODUCTION

Water is essential for life on earth. Because of the importance of water, the pattern of human settlement throughout history has often been determined by its availability. Fertile Nile river valleys with abundant water supplies were the centers for beginning civilizations. With growth, demand for water has increased dramatically, and its uses have become much more varied. Good-quality drinking water may be consumed in any desired amount without adverse effect on health. Such water is called "potable". It is free from harmful levels of impurities such as bacteria, viruses, minerals, and organic

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[1] To whom correspondence and reprint requests should be addressed. Tel.: 713-313-1912. E-mail: saleh_ma@tsu.edu

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substances. It is also aesthetically acceptable and is free of unpleasant impurities, such as objectionable taste, color, turbidity, and odor. The most common problems in household water supplies may be attributed to hardness, iron, sulphides, sodium chloride, acidity, and disease-producing pathogens, such as bacteria and viruses.

Most natural water supplies contain at least some hardness due to dissolved calcium and magnesium salts. Other minerals, such as iron, may contribute to the hardness of water, but in natural water, they are generally present in insignificant quantities. The total hardness of water may range from trace amounts to hundreds of milligrams per liter. The presence of iron and manganese in large quantities is very easy to notice because of the reddish brown stain these minerals cause. The stain shows on laundry, sinks, and every other object touched by the water. Iron is transported by water in a ferrous state forming a clear, colorless solution until it comes into contact with oxygen. Oxygen changes iron to the ferric state which reacts with alkalinity in the water and forms an insoluble brown ferric hydroxide precipitate called "yellow boy". Iron and manganese occur naturally in groundwater, but some iron can be added to the water from corroded pipes. Iron and manganese in combination with natural or man-made organic compounds will cause even more staining problems. Organic compounds react with iron and manganese to form very stable and difficult-to-remove darkly colored materials. In addition to staining problems, large amounts of these metals can influence the taste of water and cause the development of iron and manganese bacteria, which are not a health hazard but are very unpleasant. They form masses of gelatinous and filamentous organic matter that traps the iron and manganese which they use for growth. A good indication of their presence in the system is a brown slimy growth in the toilet flush tank.

Several metal ions such as sodium, potassium, magnesium, and calcium are essential to sustain biological life. At least six additional metals, chiefly transition metals, are also essential for optimal growth, development, and reproduction. These are manganese, iron, cobalt, copper, zinc, and molybdenum, which are in small enough quantities to be considered trace elements. Trace metals function mostly as catalysts for enzymatic activity in human bodies. However, all essential trace metals become toxic when their concentration becomes excessive. Drinking water containing the above trace metals in very small quantities may actually reduce the possibility of deficiencies of trace elements in the diet. In addition to the metals essential for human life, water may contain toxic metals like mercury, lead, cadmium, chromium, silver, selenium, aluminum, arsenic, and barium. These metals can cause chronic or acute poisoning and should be eliminated from drinking water, if possible.

Over 90% of Cairo's drinking water is drawn from the Nile. The Cairo Water Authority has 16 clean water treatment plants. The finished water goes to storage or pump stations for distribution. At this point, as it enters the distribution system, Cairo's drinking water is nearly always clean, as reported by El-Gohary (1994a). However, problems in the water distribution system or storage sometimes lead to erratic water supplies and/or contaminants entering the drinking water in several areas. Erratic water pressure and unreliable supply may cause pollution from contaminated groundwater or sewage through damaged joints (Myllylä, 1995).

Groundwater which provides about 8% of Cairo's drinking water comes entirely from a semi-confined highly permeable sandy aquifer under the Nile Valley. Groundwater quality varies widely. A study in Giza surveyed groundwater throughout the governorate and found it to be of good quality, except for concentrations of iron and manganese. These contaminants impart an undesirable taste and odor to the water. Also, bacteriological testing found occasional contamination, but the levels of contamination were not quantified (El-Gohary, 1994b).

In this paper, the results of investigation of the concentration of certain pollutants in five brands of the most common commercial bottled drinking water are presented. For comparison, random samples of tap water and rain water from the Greater Cairo district of Egypt, including the city of Giza, were analyzed for the same constituents. This research was carried out to clarify some of the concerns about the quality and safety of public drinking water which is practically free as compared with bottled water which costs more than gasoline. Advertisements for bottled water in Egypt appear to indicate that bottled water is safer and more healthy than tap water.

MATERIALS AND METHODS

Sampling

Five different brands of the most popular bottled water: Safi®, Mineral®, Baraka®, Delta® and Siwa® were purchased from local markets in Egypt during the summer of 1997. Three bottles of the 1.5 L size were purchased for each brand. All brands of bottled water are sold in sealed plastic bottles. All bottles were kept sealed, and refrigerated at 4°C until the time of analysis. Tap water samples were randomly collected from three different locations in Cairo and Giza during the summer of 1997. Three replicates of 2 L each were collected from tap water faucets that were left running for at least 5 min before collecting the samples. Samples were collected also from the same locations from taps equipped with charcoal filters. Tap water was kept in sealed glass bottles, refrigerated and transferred to the laboratory for analysis. Rain water samples were collected during the month of February 1998 from both Cairo and Giza and were treated in the same way as the tap water samples. All samples were analyzed within 14 days from the time of collection. No preservatives were added to any of the collected samples.

Elemental Analysis

Except for bottled water, all samples were filtered through a 0.45 μm pore diameter membrane filter. The filtrate was acidified with nitric acid immediately following filtration to $pH < 2$. One hundred milliliter aliquots of the filtered acid-preserved samples were analyzed by ICPMS using a Hewlett-Packard (HP) 4500plus ICPMS system equipped with auto sampler, electrothermal vaporization (ETV), laser ablation, ultrasonic nebulizer, and hydride generation systems (Hewlett-Packard Co., Wilmington, DE) according to the EPA Method 200.8 (EPA, 1995). All solutions were prepared using double-distilled acids and type I water (> 18 mΩ cm) from laboratory reagent grade water systems. High-purity standards for calibration and quality control as well as reference materials were obtained from Perkin-Elmer Corporation. Ultrapure nitric and hydrochloric acids were obtained from Seastar Chemicals, Inc., Sidney BC, Canada. Quality assurance and control of data were performed according to the specified condition of the method and consisted of analysis of laboratory reagent blanks, fortified blanks and samples as a continuing check on performance. Rinse blanks and three standard solutions of all monitored elements were used at concentrations of 10, 100 and 400 ppb (μg/L). Two calibrated standard solutions at concentrations of 1 and 5 ppb (μg/L) were used for mercury determinations. Table 1 shows the isotope masses that were used for each monitored element, instrument detection limits (IDL) and relative standard deviation (R.S.D.%).

TABLE 1

Quality assurance and analysis accuracy

Element	Mass	IDL (μg/L)	Average recovery (%)	RSD (%)	Element	Mass	IDL (μg/L)	Average recovery (%)	RSD (%)
Be	9	0.008	111.0	4.77	As	75	0.06	102.5	2.25
Al	27	0.007	102.7	4.01		77			4.02
Ti	47			4.81		83			7.78
	48			1.38	Se	82	0.15	93.5	3.60
	49			2.32	Mo	95	0.003	98.6	1.08
V	51	0.02	97.5	3.17		97			1.84
Cr	52	0.06	99.5	1.17		98			1.64
	53			0.70		99			39.85
Fe	54			2.08	Ag	107	0.002	99.0	1.13
	57			2.91		109			0.44
Mn	55	0.002	95.8	2.32	Cd	106			1.07
Co	59	0.001	93.6	0.45		108			3.85
Ni	60	0.004	95.2	0.05		111	0.02	101.5	1.39
	61			3.80		114			0.39
	62			3.43	Sb	121			2.31
Cu	63	0.005	91.6	0.94		123	0.002	100.8	1.39
	65			1.39	Ba	137	0.008	95.6	0.81
Zn	66	0.02	96.4	1.26		138			1.68
	67			2.13	Hg	200			2.50
	68			1.18		202	0.02	98.6	24.50
	70			13.8	Ti	203	0.0004	98.5	1.95
						205			0.93
					Pb	206			1.58
						207			2.45
						208	0.004	99.0	1.91

Ion Chromatography

Ion chromatography was carried out using a Dionex gradient HPLC system (Sunnyvale, CA) equipped with a CD20 conductivity detector. Isocratic separations of both cations and anions were performed on CS12 and AS 14 analytical columns, respectively. Dedicated guard columns and suppressor systems to either cationic or anionic analyses were also used in connection with the analytical columns. Methanesulphonic acid (20 mM) was used as the mobile phase for eluting cations, while a mixture of 3.5 mM Na_2CO_3/1.0 mM $NaHCO_3$ was used as the mobile phase for eluting the anions. Data acquisition and instrument settings were performed by Peaknet software (Dionex, CA). Primary calibration standard solutions (1000 ppm) for ions were prepared from their ultra-pure salts. Working standard solutions were prepared from the primary solutions following proper serial dilutions. Methanesulphonic acid (MSA) was purchased from Acros (Acros Organics, NJ, U.S.A.). Nitric acid, sodium carbonate, and sodium bicarbonate were of reagent grade. All calibrated solutions and standards were prepared in deionized water (Millipore, Bedford, MA, U.S.A.).

Ion Selective Electrodes (*ISE*) *Analysis*

Water samples used for ion selective electrodes analysis were mixed with the ionic strength adjustor of the selected ISE. The ion selective electrodes used were cyanide combination electrode (Model 96-06), ammonia electrode (Model 95-12), combination fluoride electrode (Model 96-09), and nitrite electrode (Model 9346) with a single-junction reference electrode model 90-01(all electrodes were from Orion, MA). Conductivity cell (Model 0 17010) and a pH meter were also used. These electrodes were connected to an EA907 expandable ion analyzer (Orion, MA). Ion selective electrodes were checked, filled with their filling solution and measured for electrode slope, where the slope was defined as the change in millivolts per 10-fold change in concentration. The difference between the two readings was the slope of the electrode. Calibrating standards for ISE were made up from 1000 ppm ready-made stock solutions purchased as certified reference standards from Fisher Scientific NH. Conductivity and pH measurements were carried out at the time of collection.

Gas Chromatography (*GC*) *and Gas Chromatography/Mass Spectrometry* (*GC/MS*) *Analysis*

Trihalomethanes were determined by headspace GC and electron capture detection according to the USEPA method 8010 using an HP 5890 Series II plus gas chromatograph attached to an HP 7694 headspace sampler and a ^{63}Ni electron capture detector. Identification of the individual components was also confirmed using an HP 5972 mass selective GC/MS system.

RESULTS AND DISCUSSION

Elemental analysis of water samples was carried out using ICPMS. The results are shown in Table 2 and Figures 1–3. Twenty-seven elements were analyzed with a mass range from 9 for beryllium to 208 for lead. Arsenic, selenium, silver and thallium were below detection limits in all of the samples and are reported as zero concentration. Elements including sodium, potassium, calcium, magnesium, silicon, phosphorus and aluminum were found at part per million levels and are reported as mg/L (Fig. 1). Vanadium, manganese, chromium, copper, zinc, titanium, nickel, molybdenum, iron and barium were found at part per billion (ppb) levels and are reported as μg/L (Fig. 2). Cobalt, antimony, lead, mercury, cadmium and beryllium were found at part per trillion (ppt) levels and are reported as ng/L (Fig. 3). A comparison of the concentration of different elements between the samples is discussed for each individual element.

Aluminum

The aluminum concentration in tap water was much higher than that found in all brands of bottled and rain water. Aluminum salts are widely used in water treatment as flocculates. The level of aluminum in drinking water from the tap was lower than the WHO-recommended level (0.2 mg/L). In some studies, aluminum appeared to be associated with brain lesions characteristic of Alzheimer disease, and in a few ecological, epidemiological studies the incidence of this disease has been associated with aluminum in drinking water (Gardner and Gunn, 1991). According to WHO (1996), a concentration of aluminum to the extent of 0.2 mg/L in drinking water provides a compromise between the practical use of aluminum salts in water treatment and discoloration of distributed water.

Antimony

Bottled water contained higher levels of antimony with Baraka® and Siwa® having the highest levels. Tap water contained similar levels of antimony as did rain water.

TABLE 2

Concentration of elements in drinking water from Egypt (per L)

Element (units)	Tap water Giza	R.S.D. (%)	Filtered Giza	R.S.D (%)	Tap water Cairo	R.S.D. (%)	Filtered Cairo	R.S.D. (%)	Rain water Giza	R.S.D. (%)	Rain water Cairo	R.S.D. (%)	Mineral®	R.S.D. (%)	Safi®	R.S.D. %	Baraka®	R.S.D. (%)	Delta®	R.S.D. (%)	Siwa®	R.S.D. (%)
Beryllium (μg)	0.02	3.83	0.02	2.40	0.02	30.3	0.02	24.9	0.03	20.1	0.03	22.4	0.02	4.77	bdl^1		bdl^1		0.02	2.45	0.01	1.98
Sodium (mg)	33.7	4.40	34.0	1.82	36.0	8.28	35.4	6.01	1.69	4.27	2.38	5.45	169	4.49	32.9	5.90	67.2	6.23	34.5	7.44	43.8	6.84
Magnesium (mg)	11.7	3.43	12.1	1.78	16.2	26.9	16.4	17.2	0.13	4.85	0.10	30.6	1.54	2.47	8.15	3.43	23.3	4.22	11.5	5.21	6.85	4.59
Aluminum (μg)	131	3.97	144	1.65	125	13.0	57.3	6.27	3.95	6.64	4.95	21.9	13.3	4.01	11.9	3.88	2.71	2.96	3.51	4.36	11.0	2.68
Silicon (mg)	2.62	3.35	1.63	2.29	1.87	7.10	1.20	7.89	1.14	8.08	1.01	6.40	11.5	2.58	12.3	3.48	17.2	4.23	17.1	2.89	11.6	3.45
Phosphorus (μg)	bdl^1		bdl^1		bdl^1		bdl^1		bdl^1		bdl^1		bdl^1		bdl^1		bdl^1		20.7	6.80	3.92	0.25
Potassium (mg)	5.58	2.07	5.67	0.48	6.09	3.09	6.23	3.49	0.11	2.94	0.03	2.67	4.88	2.02	21.2	3.54	5.33	4.96	4.06	6.61	18.5	4.97
Calcium (mg)	30.5	1.39	32.6	2.74	37.2	13.2	37.6	13.5	0.79	3.73	0.56	11.2	44.8	2.66	7.88	1.39	20.7	2.33	27.2	2.45	6.02	3.64
Titanium (μg)	90.9	2.76	98.8	1.52	111	24.8	112	21.2	2.53	8.45	1.86	6.25	136	1.38	23.4	2.76	60.8	3.12	80.4	6.88	17.7	4.30
Vanadium (μg)	5.36	2.70	5.18	1.89	5.62	12.4	5.49	9.01	0.20	4.42	0.13	7.48	4.59	3.17	1.51	2.70	2.51	2.22	7.00	3.21	1.49	1.98
Chromium (μg)	6.99	2.19	7.43	2.33	8.28	6.65	9.18	5.84	0.96	3.13	0.23	4.45	14.9	1.17	5.45	2.19	8.92	3.05	10.4	4.06	5.40	6.01
Iron (μg)	79.3	7.96	68.0	7.24	67.2	5.36	62.3	2.60	bdl^1		bdl^1		121	3.21	60.9	1.45	79.0	1.24	40.1	1.25	99.3	3.68
Manganese (μg)	6.50	0.81	5.91	1.59	3.90	4.30	2.34	13.3	0.16	5.94	0.27	12.6	0.05	2.32	1.41	1.44	bdl^1		0.33	6.23	bdl^1	
Cobal (μg)	0.17	1.49	0.13	2.08	0.15	26.5	0.12	19.1	0.03	8.76	0.03	15.3	0.04	0.45	0.00	1.23	0.02	8.3	0.04	5.20	0.01	4.68
Nickel (μg)	2.21	2.80	3.08	3.12	2.85	6.03	3.18	9.09	0.63	5.16	0.60	6.99	2.24	3.43	0.55	2.80	0.53	4.12	0.88	3.98	1.24	3.99
Copper (μg)	4.46	0.51	7.56	2.03	4.72	23.7	4.35	10.4	3.52	5.43	0.74	6.74	10.5	1.39	2.92	1.49	4.63	2.49	2.65	2.55	4.14	3.01
Zinc (μg)	11.4	1.96	184	2.04	155	12.5	333	7.69	39.2	17.6	15.1	9.23	8.19	2.13	58.8	4.40	4.85	3.12	9.26	6.27	64.1	4.97
Arsenic (μg)	bdl^1		bdl^1		bdl^1		bdl^1		0.71	7.91	0.23	1.68	bdl^1		bdl^1		bdl^1		bdl^1		bdl^1	
Selenium (μg)	bdl^1		bdl^1		bdl^1		bdl^1		bdl^1		bdl^1		bdl^1		bdl^1		bdl^1		bdl^1		bdl^1	
Molybdenum (μg)	1.42	2.95	1.53	4.36	1.53	20.9	1.62	10.6	0.08	9.21	0.08	1.82	0.35	1.84	0.29	1.38	1.86	2.08	0.88	2.12	0.36	2.64
Silver (μg)	bdl^1		bdl^1		bdl^1		bdl^1		0.00	7.52	0.00	15.5	0.12	0.44	bdl^1		bdl^1		bdl^1		bdl^1	
Cadmium (μg)	0.03	2.12	0.02	3.21	0.05	21.9	0.04	21.1	0.06	3.01	0.05	19.6	0.01	1.39	bdl^1		bdl^1		0.02	2.64	0.01	2.45
Antimony (μg)	0.08	2.1	0.11	3.22	0.09	14.4	0.08	6.05	0.09	6.56	0.06	14.1	0.19	2.31	0.18	2.10	0.28	4.35	0.10	4.21	0.30	2.22
Barium (μg)	30.4	2.26	33.7	4.52	41.2	26.1	38.9	14.9	1.55	15.7	0.72	15.8	40.1	1.68	262	2.26	59.7	3.74	11.5	5.12	222	6.91
Mercury (μg)	0.01	14.0	0.02	8.08	0.01	1.05	0.02	2.2	0.02	6.11	0.15	9.01	0.03	24.6	0.01	3.89	0.01	3.20	0.01	4.68	0.03	3.88
Thallium (μg)	bdl^1		bdl^1		bdl^1		bdl^1		0.05	3.66	0.06	7.5	bdl^1		bdl^1		bdl^1		bdl^1		bdl^1	
Lead (μg)	0.21	1.71	0.07	2.91	0.14	23.5	0.06	7.6	0.04	6.41	0.03	14.3	0.08	2.45	0.04	1.71	0.02	2.01	0.06	2.65	0.20	2.49

[1] Below detection limits.

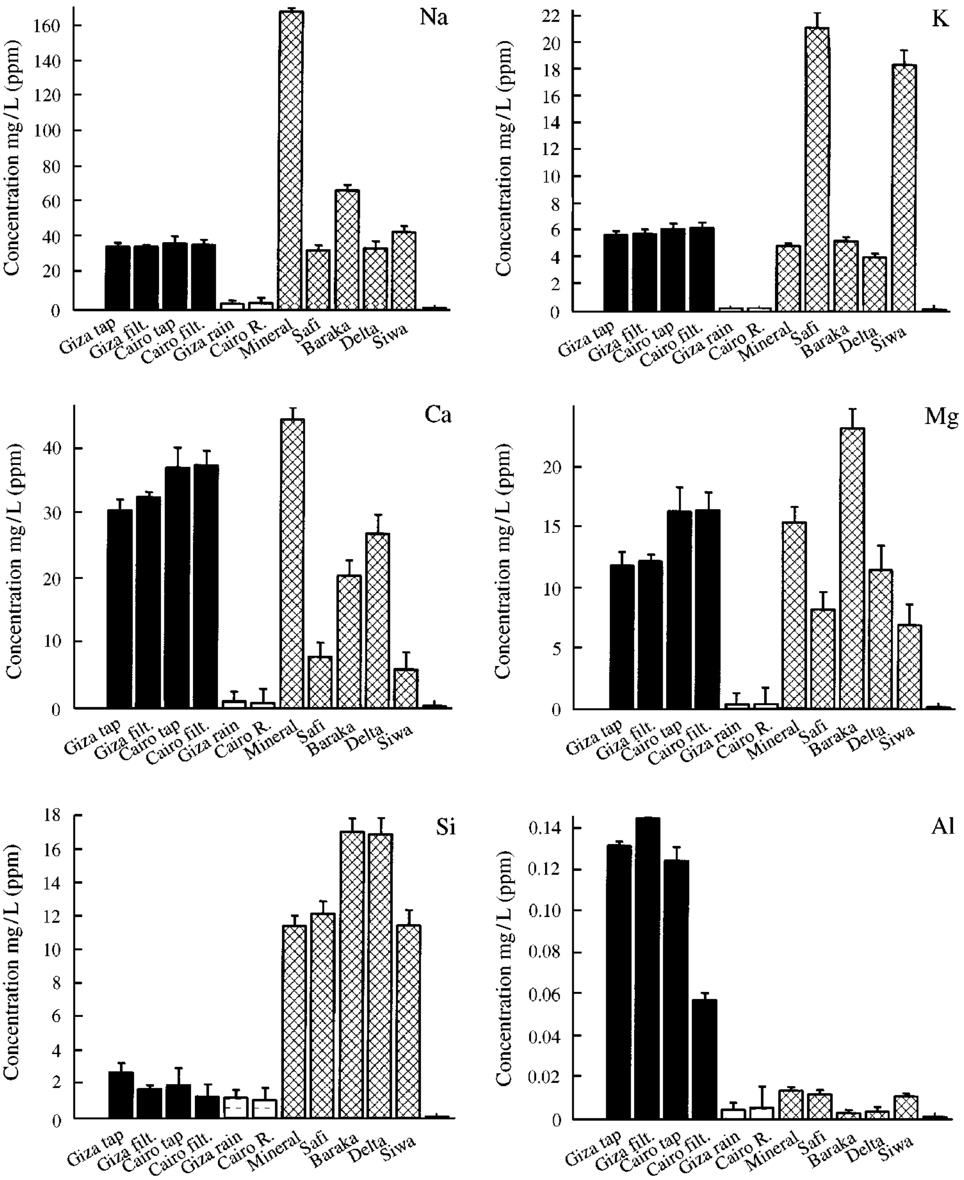

FIGURE 1. Major elements found at concentration of mg/L (ppm) levels.

Antimony has been identified in natural water in both the antimony (III) and antimony (V) oxidation states and as methyl antimony compounds. It occurs in seawater at a concentration of about 0.2 μg/L (Andreae *et al.*, 1981; Byrd and Andreae, 1982). A survey in the U.S.A. found antimony in only three of 988 samples of finished drinking water from groundwater sources, the concentrations ranging from 41 to 45 μg/L (Longtin, 1985). In a study of 3834 samples of drinking water, antimony was found in 16.5% of the samples, at concentrations ranging from 0.6 to 4 μg/L (mean 1.87 μg/L) (EPA, 1984). Therefore, in drinking water, a provisional guideline value for antimony has been set by WHO at a practical quantification level of 0.005 mg/L.

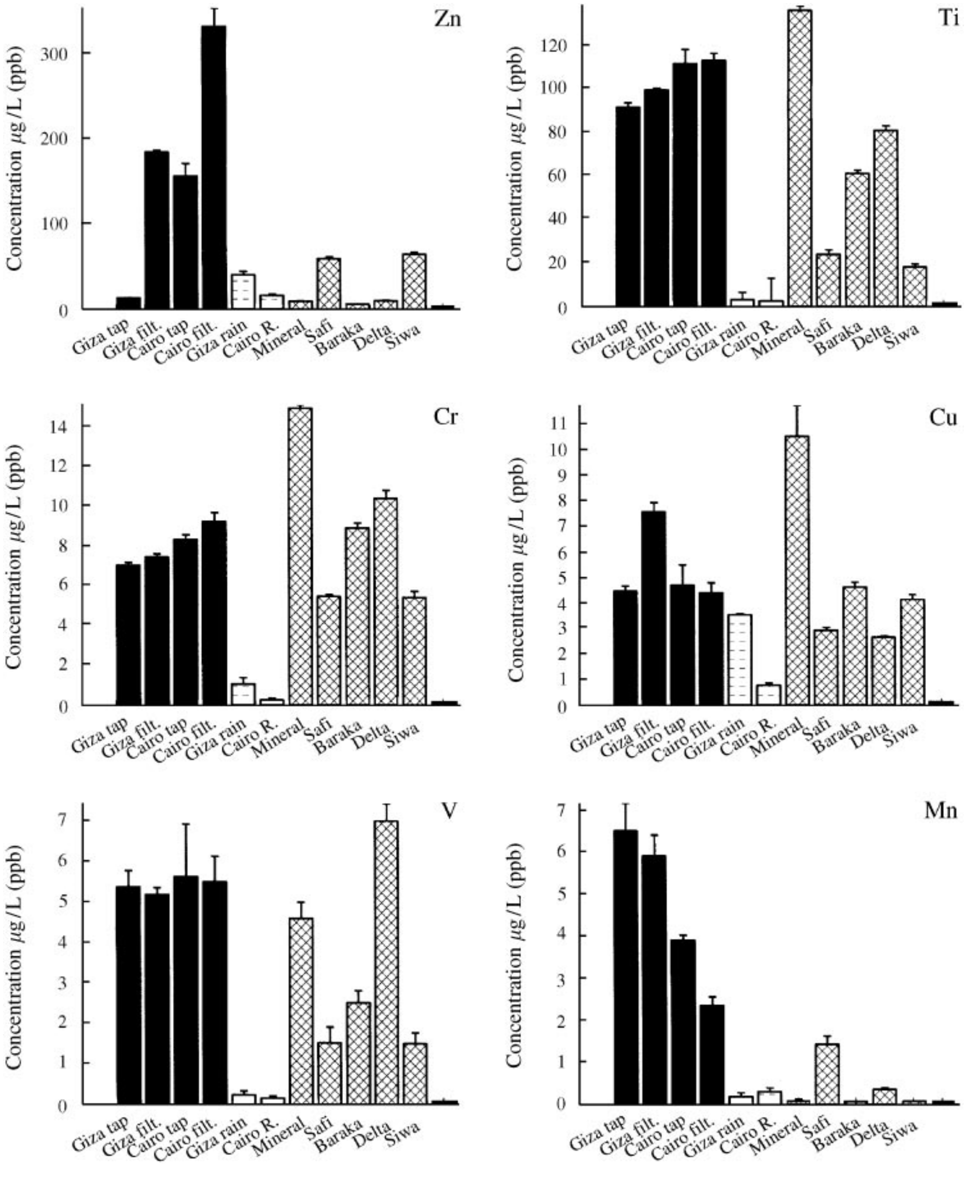

FIGURE 2. Elements found at concentrations of μg/L (ppb) levels.

Barium

Bottled water contained higher levels of barium than tap water with Siwa® and Safi® having much higher levels than other brands. Safi® water level approached the maximum recommended 700 μg/L for safe consumption. The concentration of barium in groundwater in the Netherlands was measured at 60 locations; the mean and maximum concentrations were 0.23 and 2.5 mg/L, respectively (Van Duijvenbooden,

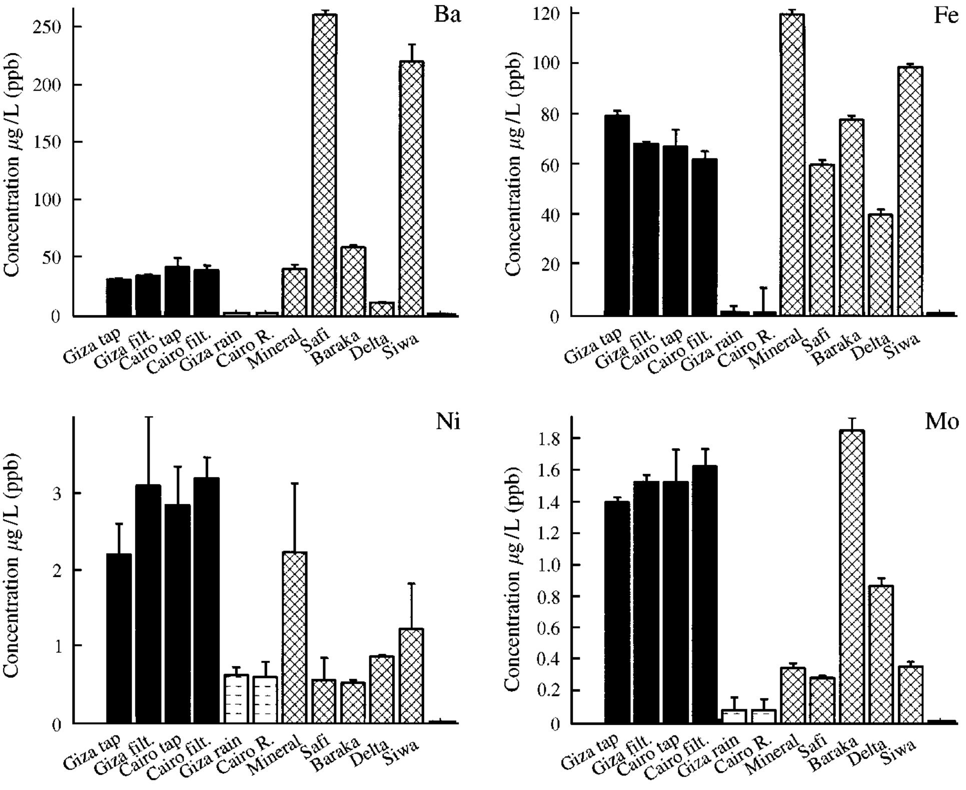

FIGURE 2. (*Continued*).

1989). Barium concentrations in distributed drinking water in Canada were found to range from not detectable to 600 μg/L, with a median value of 18 μg/L. In 86% of the 122 locations surveyed the concentrations were below 100 μg/L (Subramanian and Meranger, 1984). In 83% of 262 locations surveyed in the Netherlands in 1983, barium concentrations in drinking water were below 50 μg/L. However, the maximum concentration found was below 200 μg/L (Fonds *et al.*, 1987a). In a study of the water supplies of cities in the U.S.A., a median value of 43 μg/L was reported. In 94% of all determinations the concentrations found were <100 μg/L (WHO, 1990a). Barium is not considered to be an essential element for human nutrition (Schroeder *et al.*, 1972). At high concentrations, barium causes vasoconstriction by its direct stimulation of arterial muscle, peristalsis as a result of the violent stimulation of smooth muscle, and convulsions and paralysis following stimulation of the central nervous system (Stockinger, 1981). Associations between the barium content of drinking water and mortality from cardiovascular disease have been observed in several ecological epidemiological studies. Significant negative correlations between barium concentrations in drinking water and mortality from atherosclerotic heart disease (Schroeder and Kramer, 1974) and total cardiovascular disease (Elwood *et al.*, 1974) have been reported. Conversely, significantly higher sex- and age-adjusted death rates for “all cardiovascular diseases” and “heart disease” have been reported in an unspecified number of Illinois communities with high concentrations of barium in drinking water (2–10 mg/L) as compared with those with low concentrations (<0.2 mg/L) in 1971–1975 (Brenniman, 1979).

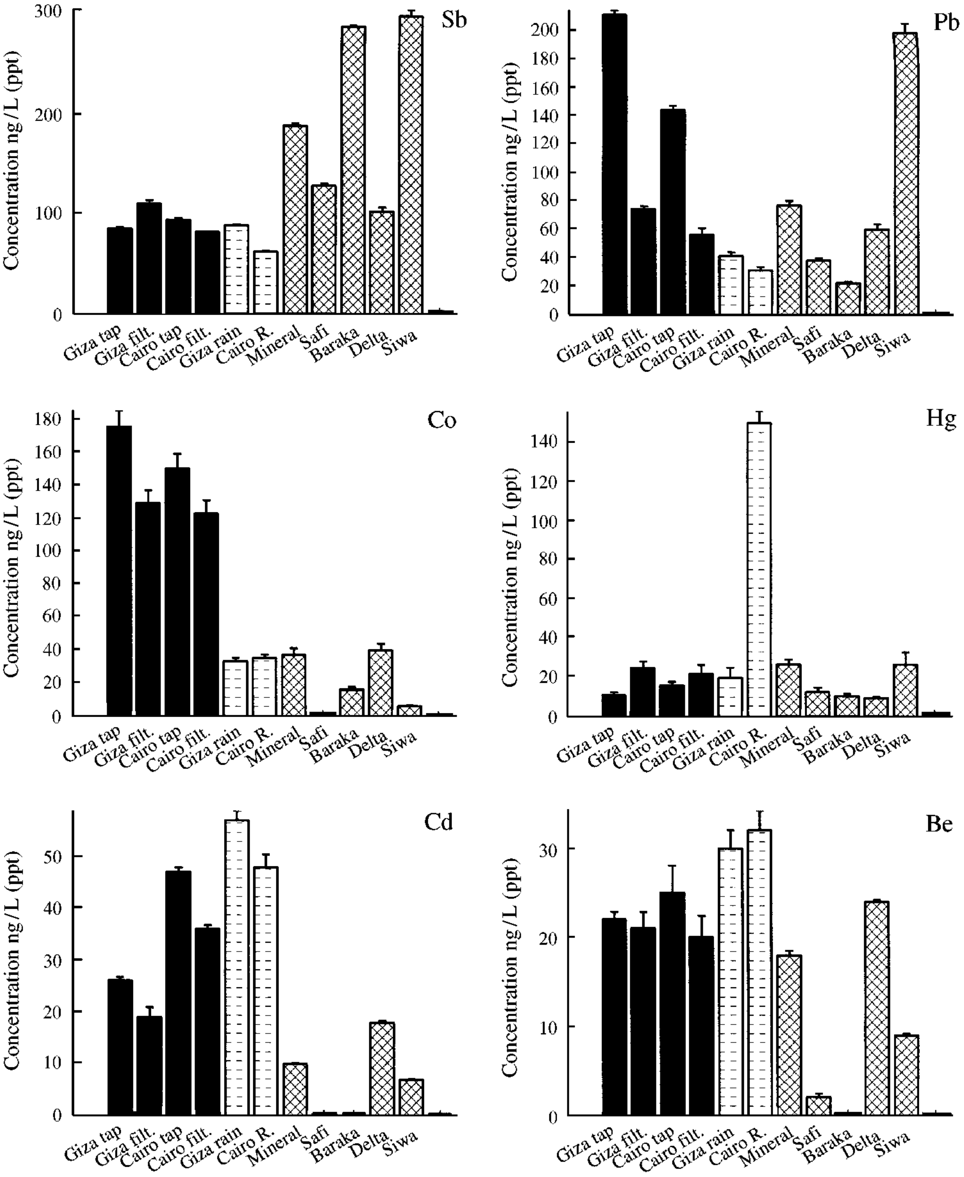

FIGURE 3. Elements found at concentrations of ng/L (ppt) levels.

A guideline value of 0.3 mg/L for barium in drinking water was proposed by WHO (1996).

Beryllium

Beryllium concentrations in tap and bottled water were within the same range except for Baraka®, which showed no detectable level. Rain water was again higher in concentration than all others. Beryllium enters natural waters through the weathering of rocks, atmospheric fallout, and industrial and municipal discharges (WHO, 1990b). Concentrations in natural waters are generally less than 1 μg/L (WHO, 1990b; Skilleter, 1987). Beryllium is rarely detected in drinking water and then only at very low concentration. In a large-scale survey in the United States, mean and maximum concentrations of 0.2 and 1.2 μg/L, respectively, were reported (National Academy of Sciences, 1977). There are no suitable oral data on which a toxicologically supportable guideline value could be based. However, the very low concentrations of beryllium normally found in drinking water seem unlikely to pose a hazard to consumers according to WHO (1996).

Cadmium

The cadmium level was slightly higher in tap water than in bottled water but rain showed the highest level among all samples. Acute cadmium-poisoning symptoms are similar to those of food poisoning. Up to 325 mg/L of cadmium is not fatal, but toxic symptoms occur at 10 mg/L. It is associated with kidney disease and linked to hypertension. There is also some evidence that cadmium can cause mutations. The cadmium concentration in unpolluted waters is usually below 1 μg/L (Friberg *et al.*, 1986). Median concentrations of dissolved cadmium measured at 110 stations around the world were <1 μg/L, the maximum value recorded being 100 μg/L in Rio Rimao in Peru (WHO, 1989). Contamination of drinking water may occur as a result of the presence of cadmium as an impurity in the zinc of galvanized pipes or cadmium-containing solders in fittings, water heaters, water coolers, and taps. The WHO Guideline value for cadmium in drinking water is 3 μg/L.

Calcium

Calcium concentrations in tap water from Cairo and Giza were similar. Rain water showed very low levels of calcium and bottled water was generally lower in calcium concentration than tap water except for Mineral® water which had slightly higher levels. Natural water sources typically contained concentrations of up to 10 mg/L for calcium. However, concentrations of up to 100 ppm are fairly common in natural sources of water (National Academy of Sciences, 1977). The taste threshold for the calcium ion is in the range 100–300 mg/L, depending on the associated anion, but higher concentrations are acceptable to consumers. Hardness levels above 500 mg/L are generally considered to be aesthetically unacceptable, although this level is tolerated in some communities (Zoeteman, 1980). Calcium is one of the major elements responsible for water hardness. Water containing less than 60 ppm of Ca is considered as soft water. Therefore, none of the analyzed samples are considered as hard water. There does not appear to be any convincing evidence that water hardness causes adverse health effects in humans. In contrast, the results of a number of epidemiological studies have suggested that water hardness may protect against disease (Derry *et al.*, 1990; Bound, 1981; Wigle, 1986).

Chromium

The chromium concentration was found to be similar in tap water and bottled water except in the Mineral® brand where the concentration was significantly higher than in other brands. All samples examined contained lower concentration than the current guideline value of 0.05 mg/L. Approximately 18% of the population of the U.S.A. is exposed to drinking water levels of chromium between 2 and 60 μg/L and $<0.1\%$ to levels between 60 and 120 pg/L (EPA, 1987a). In the Netherlands, the chromium concentration of 76% of the supplies was below 1 μg/L and of 98% below 2 μg/L (Fonds *et al.*, 1987b). A survey of Canadian drinking water supplies gave an overall median level of 2 μg of chromium per liter, with maxima of 14 μg/L (raw water) and 9 μg/L (treated water) (Meranger *et al.*, 1979). As a practical measure, 0.05 mg/L, which is considered to be unlikely to pose significant risks to health, has been retained as the provisional guideline value by WHO until additional information becomes available and chromium can be re-evaluated.

Cobalt

Cobalt was relatively higher in tap water than in any of the bottled brands but still below a dangerous level.

Copper

None of the samples analyzed contained any levels higher than the recommended maximum level of 2.0 mg/L. Copper concentrations were again similar in tap water and bottled water except in the Mineral® brand, which contained more than twice as much as the other bottled samples. Rain water from Giza had much higher levels than rain water from Cairo.

Dissolved copper imparts a color and an unpleasant astringent taste to drinking water (Page, 1973). Staining of laundry and plumbing fixtures occurs when copper concentrations in water exceed 1 mg/L. The taste threshold is above 5 mg/L, although taste is detectable in distilled water at 2.6 mg/L (Cohen, 1960). Natural copper concentrations in drinking water are around a few micrograms per liter (EPA, 1987c). This depends on such properties as hardness, pH, anion concentrations, oxygen concentration, temperature, and the technical conditions of the pipe system (Page, 1973). Short-term exposure may result in gastrointestinal distress. Long-term exposure may produce liver or kidney damage. Copper is highly toxic and very dangerous to infants and to people with certain metabolic disorders. Uptake of copper is also influenced by zinc, silver, cadmium, and sulphate in the diet.

Iron

Iron was relatively higher in bottled water than in tap water. Mineral® water had the highest iron levels among the bottled water with concentration levels of about 120 μg/L. An iron concentration of 40 μg/L can be detected by taste in distilled water. In mineralized spring water with a total dissolved solid content of 500 mg/L, the taste threshold value was 0.12 mg/L. In well water, iron concentrations below 0.3 mg/L were characterized as unnoticeable. Iron promotes undesirable bacterial growth in waterworks and distribution systems, resulting in the deposition of a slimy coating on the piping (Department of National Health and Welfare, 1990). The value of 2 mg/L recommended by WHO does not pose a hazard to health. The taste and appearance of drinking water will usually be affected below this level, although iron concentrations of 1–3 mg/L are acceptable for people drinking anaerobic well water (International Organization for Standardization; ISO 6332, 1988).

Lead

Although tap water from Giza was high in lead levels, it is still below the recommended WHO guideline value of 10 μg/L. Siwa® water was much higher in lead than any other bottled water. It is interesting to observe that the filtration of water through charcoal filters lowered the lead level significantly. Lead is present in tap water to some extent as a result of its dissolution from natural sources but primarily from household plumbing systems in which the pipes, solder, fittings, or service connections to homes contain lead. Polyvinyl chloride (PVC) pipes also contain lead compounds that can be leached from them and result in high lead concentrations in drinking water. The amount of lead dissolved from the plumbing system depends on several factors, including the presence of chloride and dissolved oxygen, pH, temperature, water hardness, and standing time of the water (Schock, 1989, 1990). Although lead can be leached from lead piping indefinitely, it appears that the leaching of lead from soldered joints and brass taps decreases with time (Levin *et al.*, 1989). In 1988, it was estimated that a lead level of 5 μg/L was exceeded in only 1.1% of public water distribution systems in the U.S.A. (EPA, 1988). A more recent review of lead levels in drinking water in the U.S.A. found the geometric mean to be 2.8 μg/L (Levin *et al.*, 1989). The median level of lead in drinking water samples collected in five Canadian cities was 2.0 μg/L (Dabeka *et al.*, 1987). A survey in Ontario (Canada) found that the average concentration of lead in water actually consumed over a 1 week sampling period was in the range 1.1–30.7 μg/L, with a median level of 4.8 μg/L (Department of National Health and Welfare, Canada, 1992).

In 1986, the joint FAO/WHO Expert Committee on Food Additives (JECFA) established a provisional tolerable weekly intake (PTWI) of 25 μg of lead per kg of body weight (equivalent to 3.5 μg/kg of body weight per day) for infants and children which took account of the fact that lead is a cumulative poison so that any increase in the body burden of lead should be avoided (FAO/WHO, 1987). The PTWI was based on metabolic studies in infants (Ziegler, 1978; Rye, 1983). The guideline value was recommended at 0.01 mg/L.

Magnesium

No significant difference in magnesium concentrations between tap water and bottled water was detected. Rain water did not have a significant amount of magnesium. An average adult ingests as much as 480 mg of magnesium daily; excess amounts are quickly expelled by the body. No upper limit has been set for this metal in drinking water. Estimated daily intakes of 2.3 and 52.1 mg of magnesium in soft- and hard-water areas have been reported, based on adults drinking 2 L of water per day (Neri, 1985).

Manganese

Manganese is found at a much higher level in tap water but still at a level much lower than that recommended by the WHO (1996). Bottled water contains significantly low levels of manganese with Safi® having the highest level in the group with a concentration of about 2 μg/L. Excess manganese in a diet prevents the use of iron in the regeneration of blood hemoglobin. Large doses of manganese cause apathy, irritability, headache, insomnia, and weakness of the legs. Psychological symptoms may also develop including impulsive acts, absent-mindedness, hallucinations, aggressiveness, and unaccountable laughter. Finally, a condition similar to Parkinson disease may develop.

In the United States, in a number of public drinking water surveys, mean manganese levels ranging from 0.004 to 0.03 mg/L were reported (Agency for Toxic Substances and Disease Registry, 1992). In Germany, the drinking water supplied to 90% of all households contained less than 0.02 mg of manganese per liter (Umwelt-Survey, 1991). No signs of toxicity were observed in patients given 30 mg of manganese citrate

(9 mg of manganese) per day for many months (Schroeder *et al.*, 1966). The guideline value of 0.5 mg/L was claimed to be adequate to protect public health according to WHO (1996).

Mercury

Mercury levels in all samples were below 30 ppt (30 ng/L) and much lower than the recommended guideline value of 1 μg/L. However, rain water from Cairo contained much higher levels (150 ng/L) of mercury than any of the water samples that were analyzed in this study. Levels of mercury in rain water were in the range 5–100 ng/L, but mean levels as low as 1 ng/L have been reported (Wood and Wang, 1983).

Naturally occurring levels of mercury in groundwater and surface water were less than 0.5 μg/L, although local mineral deposits may produce higher levels in groundwater. In 16 groundwater and 16 shallow wells surveyed in the U.S.A., mercury levels exceeded the maximum contaminant level of 2 μg/L set by the US Environmental Protection Agency for drinking water (Ware, 1989). An increase in the mercury concentration up to 5.5 μg/L was reported for wells in Izu Oshima Island (Japan), where volcanic activity is frequent (Magara, 1989). The concentration range for mercury in drinking water was the same as in rain water, with an average of about 25 ng/L (Wood and Wang, 1983).

In 1972, JECFA established a provisional tolerable weekly intake (PTWI) of 5 pg/kg of body weight of total mercury, of which no more than 3.3 pg/kg of body weight should be present as methylmercury (FAO/WHO, 1978). This PTWI was reaffirmed in 1978 (FAO/WHO, 1978). In 1988, JECFA reassessed methylmercury, as new data had become available; it confirmed the previously recommended PTWI for the general population, but noted that pregnant women and nursing mothers were likely to be at greater risk from the adverse effects of methylmercury. The guideline value for total mercury is 0.001 mg/L (FAO/WHO, 1989).

Molybdenum

Tap water from both Cairo and Giza contained approximately 1.4 μg/L of molybdenum, which is similar to the concentration of Mo in the U.S.A. drinking water (WHO, 1996). The concentration of molybdenum in bottled water was lower than that in tap water except for Baraka® which had a slightly higher level. Molybdenum was present in 32.7% of surface water samples from 15 major river basins in the U.S.A. at concentrations ranging from 2 to 1500 μg/L (mean of 60 μg/L) (Kopp and Kroner, 1967). Levels in groundwater ranged from undetectable to 270 μg/L in another survey in the U.S.A. (Kehoe *et al.*, 1994). In a survey of finished water supplies in the U.S.A., concentrations ranged from undetectable to 68 μg/L (Durfor and Becker, 1964). In another survey of 380 finished water samples from across the U.S.A., 29.9% contained measurable concentrations of molybdenum, with a mean of 85.9 μg/L and a range of 3–1024 μg/L (Kopp and Kroner, 1967). Levels of molybdenum in drinking water do not usually exceed 10 μg/L (Greathouse and Osborne, 1980). However, in areas near molybdenum mining operations, the molybdenum concentration in finished water can be as high as 200 μg/L. Tap water molybdenum concentrations as high as 580 μg/L have been reported in Colorado (Chappell, 1973). A guideline value of 0.07 mg/L was proposed by WHO (1996).

Nickel

All samples analyzed contained much lower levels of nickel than the maximum suggested concentration of 0.02 mg/L. Rain water contained detectable amounts of nickel. Mineral® water has the highest level of nickel among bottled water samples. Nickel concentrations in drinking water around the world are normally below 20 µg/L, although levels up to several hundred micrograms per liter in groundwater and drinking water have been reported (Grandjean, 1984). Nickel concentrations in drinking water may be increased if raw waters are polluted by natural or industrial nickel deposits or if leaching from nickel–chromium-plated taps and fittings occurs. Levels up to 1000 µg/L have been reported in first-run water that had remained in the tap overnight (McNeely *et al.*, 1972).

Phosphorus

Only Baraka® and Siwa® showed phosphorus. This was consistent also with the fact that they were the only samples detected as phosphate in the ion chromatography analysis for anions.

Silicon

The silicon level in tap and rain water was very low (less than 2 mg/L). All brands of bottled water contained substantial amounts of silicon that was estimated to be about 10 times greater than that found in tap water. No health effect of silicon has been reported by WHO and no proposed guideline level is available.

Sodium

Sodium concentration in tap water was at a very similar level in samples collected from tap water in Cairo and Giza, which was at approximately 33 mg/L. Filtration of the water through charcoal filters did not have any effect on the sodium level. Rain water as expected contained a very low level of sodium (2.5 mg/L). Sodium concentration of bottled water was similar to that of tap water except for the Mineral® brand where the concentration was above 160 mg/L and for Baraka® at 67 mg/L, as shown in Figure 1. Sodium levels in the drinking water of the U.S.A. are typically less than 20 mg/L. According to the WHO guidelines for maximum concentration level of sodium in drinking water, only Mineral® water exceeded that recommendation, with a value of 160 mg/L (WHO, 1996). Sodium may affect the taste of drinking water at levels above 200 mg/L (WHO, 1979).

Titanium

Overall, titanium was higher in tap water than in bottled water except for the sample from Mineral® which showed a higher level than tap water. Filtration of water slightly increased the level of titanium. No guideline value is available for titanium.

Vanadium

Vanadium concentration in tap water was about 5 µg/L and was slightly lower in bottled water except for the Delta® sample. No health effect from drinking water has been reported.

Zinc

Zinc was higher in tap water than in bottled water but both are within the levels recommended for good health. It is interesting to note that the filtration of water actually increased the level of zinc in tap water possibly due to some leaching from materials used in manufacturing the filters.

According to Cohen (1960) zinc imparts an undesirable astringent taste to water. Tests indicate that 5% of a population can distinguish between zinc-free water and water containing zinc (as zinc sulphate) at a level of 4 mg/L. The detection levels for other zinc salts were somewhat higher. Water containing zinc at concentrations in the range 3–5 mg/L also tends to appear opalescent and develops a greasy film when boiled (Cohen, 1960).

ION CHROMATOGRAPHY AND ION SELECTIVE ELECTRODES ANALYSIS

The results of water analysis by ion chromatography (IC) and ion-selective electrodes are shown in Table 3 and Figure 4. No ammonia or cyanide was detected in any of the samples. The results for each individual anion are discussed below.

Acidity

The pH of water for all samples was slightly basic being approximately 8 except for rain water from Cairo and Giza where it is slightly lower (7.7–7.8).

Conductivity

Conductivity values for tap water were similar, at about 550 pS/cm. The Mineral® and Baraka® brands showed higher values than tap water.

Bromide

Bromide was not detected in any of the tap water or rain water samples. Bottled water from Safi®, Delta® and Siwa® contained similar concentrations of bromide in approximately 0.25 mg/L range. However, Mineral® water showed a much higher amount in the range of 1.8 mg/L and Baraka® water showed about 0.6 mg/L.

Chlorides

Tap water from Giza contained less than 30 mg/L of chloride. However, Cairo water was about twice as high in chloride. Bottled water was close to that of Giza tap water except for Mineral® water which showed a much higher level (221 mg/L). The taste threshold of the chloride anion in water is dependent on the associated cation. Taste thresholds for sodium chloride and calcium chloride in water are in the range 200–300 mg/L (Zoeteman, 1980). The taste of coffee is affected if it is made with water having a chloride concentration of 400 mg/L as sodium chloride or 530 mg/L as calcium chloride (Lockhart *et al.*, 1955). Chloride in surface water and groundwater originates from both natural and anthropogenic sources, such as run-off containing road de-icing salts, the use of inorganic fertilizers, landfill leachates, septic tank effluents, animal feeds, industrial effluents, irrigation drainage, and seawater intrusion in coastal areas (Department of National Health and Welfare, 1978). The mean chloride concentration in several rivers in the United Kingdom was in the range of 11–42 mg/L during 1974–1981 (Brooker and Johnson, 1984). Evidence of a general increase in chloride concentrations in groundwater and drinking water has been found (Brooker and Johnson, 1984). Contaminated wells in the Philippines have been reported to have an average chloride concentration of 141 mg/L. Chloride levels in

TABLE 3

Concentration[1] of anions in drinking water from Egypt

Analytes	Tap water Giza	Filtered Giza	Tap water Cairo	Filtered Cairo	Giza Rain	Cairo Rain	Mineral®	Safi®	Baraka®	Delta®	Siwa®
Ion chromatography											
Fluoride	0.24 ± 0.02	0.22 ± 0.01	0.26 ± 0.02	0.24 ± 0.02	0.02 ± 0.00	0.01 ± 0.00	0.12 ± 0.02	0.42 ± 0.02	0.14 ± 0.00	0.19 ± 0.00	0.48 ± 0.01
Chloride	28.36 ± 0.59	30.01 ± 0.46	62.21 ± 0.28	62.38 ± 0.47	bdl[2]	bdl[2]	221.13 ± 2.20	27.13 ± 0.07	53.80 ± 0.32	11.06 ± 0.12	35.99 ± 0.26
Bromide	bdl[2]	bdl[2]	bdl[2]	bdl[2]	bdl[2]	bdl[2]	1.76 ± 0.09	0.16 ± 0.05	2.38 ± 0.18	0.14 ± 0.04	1.06 ± 0.04
Nitrate	bdl[2]	0.05 ± 0.00	0.03 ± 0.00	0.04 ± 0.00	0.1 ± 0.06	0.08 ± 0.02	18.68 ± 1.3	0.11 ± 0.09	0.10 ± 0.00	0.28 ± 0.05	0.28 ± 0.10
Phosphate	bdl[2]	bdl[2]	bdl[2]	bdl[2]	bdl[2]	bdl[2]	0.13 ± 0.07	bdl[2]	2.11 ± 0.30	0.15 ± 0.01	0.39 ± 0.01
Sulphate	59.96 ± 0.57	59.64 ± 0.47	78.16 ± 0.17	78.91 ± 0.36	0.5 ± 0.07	2.74 ± 0.01	68.12 ± 0.47	11.73 ± 0.03	53.56 ± 0.34	10.39 ± 012	17.73 ± 0.21
Ion selective Electrodes											
pH	8.1	8.0	8.1	8.4	7.6	7.8	8.2	8.2	8.5	8.4	8.2
Conductivity	598	599	598	569	42.7	47.6	985	336	710	370	344
Nitrite	bdl[2]	bdl[2]	bdl[2]	0.05 ± 0.01	0.68	0.02 ± 0.01	0.12 ± 0.03	bdl[2]	0.06 ± 0.00	0.02 ± 0.00	0.05 ± 0.01
GC/ECD GC/MS											
$CHCl_3$	190 ± 10	90 ± 5	211 ± 12	105 ± 9	bdl[2]	bdl[2]	bdl[2]	bdl[2]	86 ± 5	bdl[2]	79 ± 5
$CHCl_2Br$	101 ± 9	28 ± 2	113 ± 10	30 ± 2	bdl[2]	bdl[2]	bdl[2]	bdl[2]	73 ± 3	bdl[2]	69 ± 4
$CHClBr_2$	67 ± 5	22 ± 2	71 ± 4	32 ± 3	bdl[2]	bdl[2]	bdl[2]	bdl[2]	60 ± 3	bdl[2]	bdl[2]

[1] Concentrations are expressed as mg/L for all of the anions, as μg/L for trihalomethanes and as μS/cm for conductivity.

[2] bdl = below detection limits.

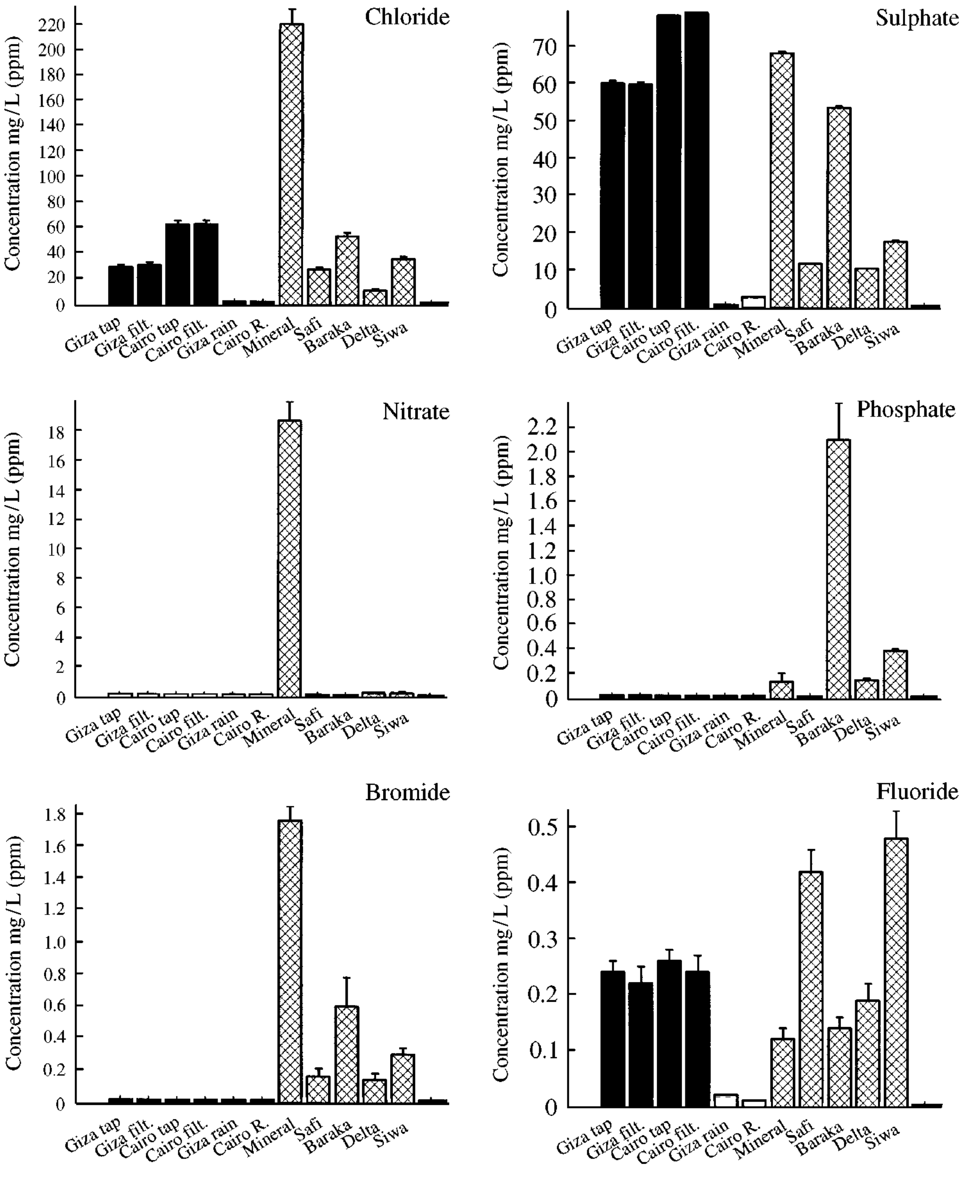

FIGURE 4. Concentration of anionic species in water.

unpolluted waters are often below 10 mg/L and sometimes below 1 mg/L (Department of National Health and Welfare, 1978). Chloride in water may be considerably increased by treatment processes in which chlorine is used. Chloride concentrations in excess of about 250 mg/L can give rise to detectable taste in water, but the threshold depends on the associated cations. However, consumers can become accustomed to concentrations in excess of 250 mg/L. No health-based guideline value was proposed by the WHO for chloride in drinking water.

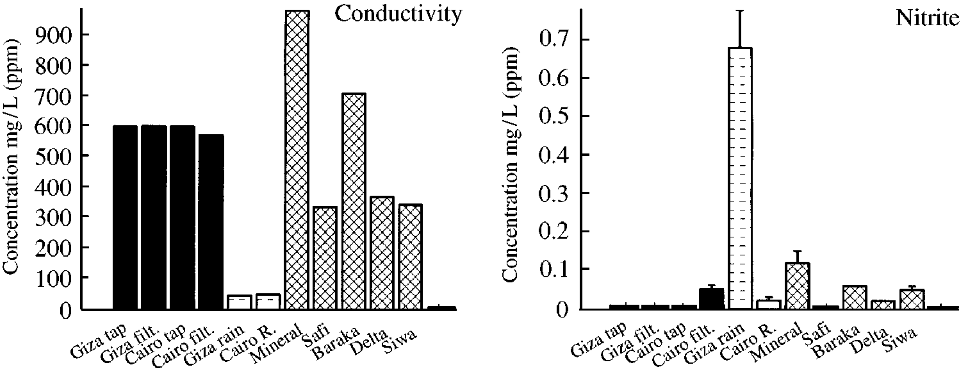

FIGURE 4. (*Continued*).

Fluorides

Tap water from Cairo and Giza averaged about 0.25 mg/L and bottled water of the Safi® and Siwa® brands contained twice as much fluorides as tap water. Traces of fluoride are present in many waters. However, higher concentrations are often associated with underground sources. In seawater, a total fluoride concentration of 1.3 mg/L has been reported (Slooff, 1988). In areas rich in fluoride-containing minerals, well waters may contain up to about 10 mg of fluoride per liter. The highest natural level reported is 2800 mg/L. Fluorides may also enter a river as a result of industrial discharges (Slooff, 1988). In groundwater, fluoride concentrations vary with the type of rock that the water flows through but do not usually exceed 10 mg/L (EPA, 1985). In the Rhine in the Netherlands, levels are below 0.2 mg/L. In the Meuse, fluoride concentrations fluctuate (0.2–1.3 mg/L) as a result of variations in industrial processes (Slooff, 1988). Fluoride concentrations in the groundwater of some villages in China were greater than 8 mg/L (Drinking Water Atlas of China, 1990). In Canada, fluoride levels in drinking water of $<$0.05–0.2 mg/L (nonfluoridated) and 0.6–1.1 mg/L (fluoridated) have been reported in municipal waters. In drinking water prepared from well water, levels up to 3.3 mg/L have been reported. In the U.S.A., 0.2% of the population is exposed to more than 2.0 mg/L (EPA, 1985). In the Netherlands, year-round averages for all drinking water plants are below 0.2 mg/L (Slooff, 1988). In some African countries where the soil is rich in fluoride-containing minerals, levels in drinking water are relatively high (e.g., 8 mg/L in the United Republic of Tanzania) (EPA, 1985). The guideline value is 1.5 mg/L set in 1984 (Murray, 1986). Concentrations above this value cause an increase in dental fluorosis, and much higher concentrations may lead to skeletal fluorosis.

Nitrates and Nitrites

None of the water samples that were analyzed showed any significant level of nitrate ions except the Mineral® samples which had abnormally high levels of nitrates, about 19 mg/L, which is higher than the WHO guideline value. The limit for nitrates in drinking water is 3 mg/L as nitrogen. This is about 13.5 mg/L of the nitrate ion. Rain water from Giza contained exceptionally high levels of nitrite ions with a concentration of about 0.7 mg/L. Tap water from both Cairo and Giza showed no detectable amounts of nitrite ions. All bottled water contained detectable amounts of nitrate except the Safi® brand which showed no detectable amounts of nitrate. Nitrite ion concentrations in bottled water range from below the detection limit in Safi® to 0.12 mg/L in the Mineral® brand. Concentrations of nitrate in rain water of up to 5 mg/L have been observed in industrial areas (Van Duijvenbooden and Matthijsen, 1989). In rural areas, concentrations were somewhat lower. The nitrate concentration in surface water is normally low (0–18 mg/L), but can reach high levels as a result of agricultural run-off, refuse dump run-off, or contamination with human or animal wastes. The concentration often fluctuates with the season and may increase when the river is fed by nitrate-rich aquifers. Nitrate concentrations have gradually increased in many European countries in the last few decades and have sometimes doubled over the past 20 years. In the United Kingdom, for example, an average annual increase of 0.7 mg/L has been observed in some rivers (Young and Morgan-Jones, 1980). The natural nitrate concentration in groundwater under aerobic conditions is a few milligrams per liter and depends strongly on soil type and geological situation. In the U.S.A., naturally occurring levels do not exceed 4–9 mg/L for nitrate and 0.3 mg/L for nitrite (EPA, 1987b). As a result of agricultural activities, the nitrate concentration can easily reach several hundred milligrams per liter (WHO, 1985). For example, concentrations of up to 1500 mg/L were found in the groundwater in an agricultural area of India (Jacks and Sharma, 1983). In the U.S.A., nitrates are present in most surface water and groundwater supplies at levels below 4 mg/L; levels exceed 20 mg/L in about 3% of the surface waters and 6% of the groundwater. In 1986, a nitrate concentration of 44 mg/L (10 mg nitrate-nitrogen per liter) was exceeded in 40 surface water and 568 groundwater supplies. Nitrite levels were not surveyed but are expected to be much lower than 3.3 mg/L (EPA, 1987b). The increasing use of artificial fertilizers, disposal of wastes (particularly from animal farming), and changes in land use are the main factors responsible for the progressive increase in nitrate levels in groundwater supplies over the last 20 years. In Denmark and the Netherlands, for example, nitrate concentrations are increasing by 0.2–1.3 mg/L per year in some areas (WHO, 1985). In most countries, nitrate levels in drinking water derived from surface water do not exceed 10 mg/L. However, in some areas concentrations are higher as a result of run-off and the discharge of sewage effluent and certain industrial wastes. In 15 European countries, the percentage of the population exposed to nitrate levels in drinking water above 50 mg/L ranges from 0.5 to 10% (WHO, 1985; European Chemical Industry Ecology and Toxicology Center, 1988). This corresponds to nearly 10 million people. Individual wells in agricultural areas throughout the world are especially vulnerable, and nitrate levels in the water often exceed 50 mg/L. Experiments suggest that neither nitrate nor nitrite acts directly as a carcinogen in animals, but there is some concern about a possible increased risk of cancer in humans from the endogenous and exogenous formation of N-nitrosoamine compounds, many of which are carcinogenic in animals. WHO guideline value for nitrate in drinking water is established solely to prevent methemoglobinemia, which depends on the conversion of nitrate to nitrite. The WHO guideline value for nitrite is 3 mg/L as nitrogen.

Because of the possibility of the simultaneous occurrence of nitrite and nitrate in drinking water, the sum of the ratios of the concentrations of each to its guideline value should not exceed 1.

Phosphate

No phosphate was detected in the drinking water and relatively low levels were detected in the bottled water except for Baraka®, which had a level of 2.1 ppm and the

Siwa® sample with about 0.4 mg/L. The results of the phosphate concentration are consistent with the value of phosphorus concentration as was determined by inductively coupled plasma mass spectrometry.

Sulphates

Sulphate concentrations in all samples were relatively similar except for Safi®, Delta®, and Siwa® bottled water where they were significantly lower. All samples contained less than 80 mg/L of sulphate. Reported taste threshold concentrations in drinking water are 250–500 mg/L (median 350 mg/L) for sodium sulphate, 250–1000 mg/L (median 525 mg/L) for calcium sulphate, and 400–600 mg/L (median 525 mg/L) for magnesium sulphate (National Academy of Sciences, 1977). In a survey of 10–20 people, the median concentrations of sulphate that could be detected by taste were 237, 370, and 419 mg/L for the sodium, calcium, and magnesium salts, respectively (Whipple, 1972). Concentrations of sulphates at which water was determined to have an "offensive taste" were approximately 1000 and 850 mg/L for calcium and magnesium sulphate, respectively (Zoeteman, 1980). Addition of calcium sulphate and magnesium sulphate (but not sodium sulphate) to distilled water was found to improve the taste. An optimal taste was found at 270 and 90 mg/L for calcium sulphate and magnesium sulphate, respectively (Zoeteman, 1980).

Sulphate concentrations in rain water in Canada varied between 1.0 and 3.8 mg/L in 1980 (Franklin, 1985). An annual mean value of about 6 mg/L in precipitation over central Europe has been reported (WHO, 1989). Levels of sulphate in rain water and surface water correlate with emission levels of sulphur dioxide from anthropogenic sources (Keller and Pitblade, 1986). According to GEMS/WATER, a global network of water-monitoring stations, typical sulphate levels in fresh water are in the vicinity of 20 mg/L and range from 0 to 630 mg/L in rivers, the highest values being found in Belgium and Mexico, from 2 to 250 mg/L in lakes (the highest value is found in Mexico), and from 0 to 230 mg/L in groundwater (the highest values are found in Chile and Morocco) (UNEP/WHO/UNESCO/WMO, 1990). Levels of sulphate in groundwater in the Netherlands were below 150 mg/L (Van Dijk and Fonds, 1985). The mean sulphate level in municipal drinking water supplies may be increased by treatment. Levels in central Canada are particularly high; in Saskatchewan, median levels of 368 and 97 mg/L were found in treated drinking water from groundwater and surface water supplies, respectively, with a range of 3–2170 mg/L (Saskatchewan Environment and Public Safety, unpubl. data, 1989).

In the Netherlands, the sulphate concentration of drinking water from 65% of water treatment plants was below 25 mg/L in 1985 (Van Dijk and Fonds, 1985). Based on the mean sulphate concentration of 22.5 mg/L in Ontario and an average daily consumption of 2 L of drinking water, the average daily intake from this source would be 45 mg. However, in areas with much higher sulphate levels in drinking water, such as Saskatchewan, daily intake from this source could be over 4000 mg.

Sulphate is one of the least toxic anions. The lethal dose for humans as potassium or zinc sulphate is 45 g (Arthur, 1971). The major physiological effects resulting from the ingestion of large quantities of sulphate are catharsis, dehydration, and gastrointestinal irritation. No health-based guideline value for sulphate in drinking water is proposed by either WHO or EPA. However, because of the gastrointestinal effects resulting from the ingestion of drinking water containing high sulphate levels, it is recommended that health authorities be notified of sources of drinking water that contain sulphate concentrations in excess of 500 mg/L.

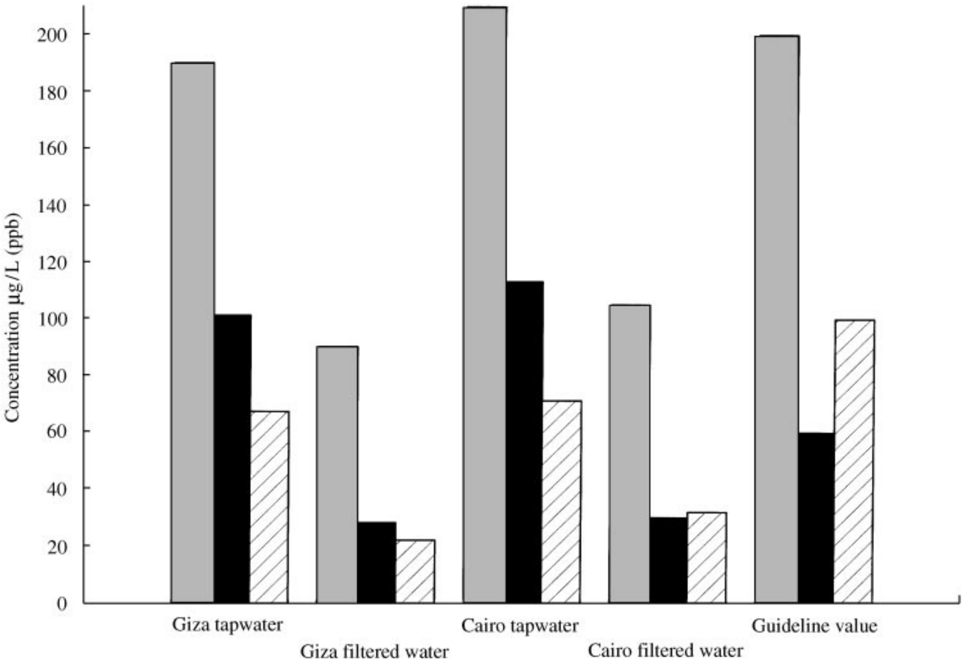

FIGURE 5. Trihalomethanes in water samples. ▒, chloroform; ■, bromodichloromethane; ▨, dibromochloromethane.

GAS CHROMATOGRAPHY/MASS SPECTROMETRY ANALYSIS (GC/MS)

Trihalomethanes were analyzed in both tap water and bottled water. The results are shown in Table 3 and Figure 5. Tap water from both Cairo and Giza showed relatively high levels of chloroform, bromodichloromethane and dibromochloromethane. The concentrations of the identified trihalomethanes were higher than the WHO guideline values for chloroform and bromodichloromethane but charcoal filtration lowered the concentrations to levels less than the guideline values. Baraka® water contained all of the three identified trihalomethanes but at lower concentrations than the WHO guideline values. Siwa® water contained only chloroform and bromodichloromethane at lower levels than Baraka® water.

CONCLUSION

All samples analyzed were free of arsenic, selenium, silver and thallium. Other elements detected were all within the WHO concentration guidelines and were also below the maximum contaminant levels (MCL) established by the USEPA. Bottled water of all brands contained higher levels of sodium, potassium, magnesium, silicon, vanadium, copper, iron and antimony than tap water. However, tap water contained higher levels of aluminum, zinc, titanium, manganese, cobalt and nickel than bottled water. The much higher level of aluminum in tap water is attributed to the use of alum in water purification. Rain water contained very low levels of elements, as expected, except for beryllium, mercury, cadmium and lead where they were higher in concentration than both tap water and bottled water. The filtration of tap water through charcoal filters did not significantly change the concentration of elements in water except for lead, cadmium and manganese where they were significantly reduced upon filtration. On the other hand, zinc was higher in the filtered tap water than before filtration. Mineral® water was the highest in total salt concentration and also showed the highest conductivity values among all of the analyzed water. Siwa® water contained relatively higher levels of lead, mercury, barium and antimony than did any other brand but still was below the dangerous health levels specified under WHO and USEPA standards.

All anions except sulphate were higher in bottled water than in tap water. None of the samples showed the presence of cyanide. Tap water was also free of bromide, nitrate, nitrite and phosphate. All detected anions were below the WHO and USEPA guideline values. Mineral® water was the only bottled water that showed a level of chloride approaching the MCL. The nitrite concentration was unusually high in the rain water from Giza. Only three of the trihalomethanes were detected in the analyzed samples. Chloroform, bromodichloromethane and dibromochloromethane were found in all tap water samples at a level close to the MCL. However, it was significantly reduced by charcoal filtration. The same three chemicals were found at much lower concentrations in Baraka® water. Only chloroform and bromodichloromethane were detected in Siwa® water. All other samples of bottled water were free of trihalomethanes. Except for microbial pathogens which were not evaluated in this study, the water quality based on the chemical constituents analyzed appears to be as good for tap water as for bottled water.

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