Environment Protection Engineering

Vol. 42 2016 No. 4

DOI: 10.5277/epe160405

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QUALITY ASSESSMENT OF 30 VARIOUS BRANDS OF BOTTLED DRINKING WATERS IN IRAN

During the last three decades bottled water consumption has become the fastest growing and most dynamic sector of all the food and beverage industries. In the study, physical, chemical and microbiological qualities of 30 different brands of bottled water were studied and compared with labeled values. Total hardness and pH values of bottled water were within acceptable range. Concentrations of trace and major chemical elements of all samples were within standard range. Nitrite concentration in all samples was close to zero. Only 6% and 20% of samples had respectively higher than acceptable values of fluorides and turbidity, respectively. Measured concentrations of sodium, calcium, magnesium, fluorides, nitrates, chlorides, pH and (TDS) were significantly different from labeled values on the samples. Twobrand bottles showed positive fecal coliform results while 16 brands of bottled water showed positive HPC results at 37 °C.

1. INTRODUCTION

Bottled water consumption, increasing steadily worldwide during the last three decade, is regarded the fastest growing and most dynamic sector of all the food and beverage industries. The worldwide consumption of bottled waters was estimated to escalate from 130 956 million liters in 2002 to 188 777 million liters in 2007; thus, the average annual global consumption rate calculates to 28.8 dm^3 per capita for the year 2007 [1]. The constantly increasing popularity of bottled waters is the result of a number of factors, the most important of which are: uncertainty of the quality and safety of tap water,

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availability, marketing strategies, the fashion for a healthy lifestyle, and increasing consumer awareness of the benefits of regularly drinking such water [2]. The average European Union consumption of bottled water was 104.2 dm^3 per capita, whereas the US bottled water market per capita consumption was 110.9 dm^3 [3]. The consumption of bottled water is rapidly rising in most countries especially in Iran. The increased demand for this water is attributed largely to factors such as inadequate safe drinking water in distribution network.

Bottled water is also utilized in emergency situation such as drought, earthquake, flood, hurricane and war which can damage public water supplies for long periods of time [4]. The popularity of bottled water can be gauged by the number of brands produced in Iran (over 100). The source of bottled water sold in Iran is from springs, wells and tap water with desalination process and UV disinfection. However, bottled water is not necessarily safer than tap water, and over the years, concerns have been raised about the quality of bottled water marketed worldwide. Some contaminations are most likely introduced in water by leaching from low-quality materials used for packing. Even the equipment and handling intensive processing of bottled water provides many opportunities for the introduction of contaminants [5].

Table 1

National and international standards
for physical and chemical constituents in bottled drinking waters

Parameter	WHO, 2006 GV	EPA, 2002 MCL	EEC, 1998 MAC[c]	ISIRI, 2005 MAC
Sodium, mg Na^+/dm^3 Potassium, mg K^+/dm^3				200
Calcium, mg Ca^{2+}/dm^3	–	–	–	250
Magnesium, mg Mg^{2+}/dm^3	–	–	–	50
Total hardness, mg $CaCO_3/dm^3$	500	–	–	500
Fluorides, mg F^-/dm^3	1.5	2	1.5	0.7–1.2
Sulfates, mg SO_4^{2-}/dm^3	–	250	250	400
Nitrates, mg NO_3^-/dm^3	50	44	50	50
Nitrites, mg NO_2^-/dm^3	0.2	3.3	0.5	3
Chlorides, mg Cl^-/dm^3	–	250	250	–
Turbidity, NTU	–	1	–	5
pH	6.5–9.5	6.5–8.5	6.5–9.5	6.5–9
TDS, mg/dm^3	1000	500	–	1500

WHO – World Health Organization, EPA – US Environmental Protection Agency, EEC – European Economic Community, ISIRI – Institute of Standards and Industrial Research of Iran standards, GV – guideline value, MCL – maximum contaminant level, MAC – maximum admissible concentration.

National regulations relating to the requirements for bottled waters are usually based on international rules or on guideline values defined by the World Health Organization (WHO) [6]. Table 1 lists the requirements regarding organic contaminant binding in European Economic Community (EEC) [7] member states and specified by the most important international and national organizations: WHO, US Environmental Protection Agency (EPA) [8], and Institute of Standards and Industrial Research of Iran standards (ISIRI).

Several studies have documented the detection of coliforms and heterotrophic bacteria in bottled water in counts exceeding national and international standards set for water intended for human consumption [9]. As numerous studies were conducted to assess bottled water quality in neighboring countries, sporadic studies were conducted in Iran on selected bottled water brands and for few parameters only [10]. This study aims at comprehensively investigating the physico-chemical as well as microbiological quality of selected bottled waters. Recorded outcomes will assist in categorizing analyzed bottled waters by their mineral content, verifying compliance of analyzed constituents with existing national and international standards, as well as verifying compliance with reported label values and standards of identity.

2. MATERIALS AND METHODS

Sampling. Thirty brands of bottled waters were purchased in duplicate in polyethylene terephthalate containers during spring from randomly selected grocery shops and supermarkets throughout Iran. Container volume varied from 0.5 to 10 dm^3. All samples were contained in their original sealed containers and stored one week at ambient conditions (23–25 °C) prior to completing related analyses at the Department of Environmental Health, Shahroud University of Medical Sciences, Iran.

Physicochemical parameters. Standard methods [11] were used for the analyses of physicochemical water quality. Parameters analyzed were: pH, conductivity, total alkalinity, hardness, nitrate, nitrite fluoride, chloride, and sulfate contents, turbidity, calcium, magnesium, potassium, sodium, total dissolved solids (TDS) and other elements (Fe, Al, Cr, Cu, Mn, Mo, Ni, and Zn), [12]. For trace metals, water sample were acidified in nitric acid and analyzed uing VISTA MPX ICP equipped with CCD detector in axial mode. A 40-MHz R.F. generator was used as the power supply for the plasma. The excitation source was a three-turn inductively coupled plasma torch with a Cetac ultrasonic nebulizer for sample introduction.

Bacteriological parameters. Bacteriological quality of water samples was determined by using the membrane filtration, a standard method for the enumeration of total coliform (TC) and fecal coliform (FC) in water and wastewater. Water samples (100 cm^3) were

collected in sterilized bags containing sodium thiosulfate tablets to neutralize residual chlorine. FC and TC were cultured and incubated at 44.5 °C for 48 h and at 35.5 °C for 24 h, respectively, using membrane filtration techniques, whereas heterotrophic bacteria were assessed by the heterotrophic plate count method (HPC) and incubated at 37 °C. All analytical tests were performed in accordance to the standard methods for the examination of water and wastewater [13] and/or the USEPA accepted reference methods [14].

3. RESULTS AND DISCUSSION

Physical and chemical parameters of 30 examined brands of Iranian bottled water are presented in Table 2. Bottled water with different commercial brands had less homogeneous and uniform physical composition. The total water hardness was lower than 300 mg $CaCO_3/dm^3$, whose range was from 20 to 285 mg $CaCO_3/dm^3$in all samples. Range of total dissolved solids (TDS) varied from 53 to 394 mg/dm^3 (mean – 233.9 mg/dm^3) in all samples. In the present study, mean pH of water bottles was 7.5 in the range from 7.1 to 8.2. This was a standard range based on Iranian National Standards, the World Health Organization and the U.S. Environmental Protection Agency.

Concentrations of major ions and trace chemicals were at acceptable range in most bottles. Only fluoride concentration in two bottles (6% of samples) and turbidity in six bottles (20% of samples) were higher than the acceptable range. Nitrite concentration was close to zero. Calcium concentration was within a range from 8 to 100 mg Ca^{2+}/dm^3 while maximum sulfate concentration was 127 mg SO_4^{2-}/dm^3 and maximum chloride concentration was 251 mg Cl^-/dm^3. These were slightly higher than maximum level of pollutants based on U.S. Environmental Protection Agency data. Mean fluoride concentration was 0.43 mg F^-/dm^3while minimum and maximum fluoride concentrations were 0.1 and 1.25 mg F^-/dm^3, respectively.

Table 1 presents the National and International Standard Qualities of bottled drinking water. Concentrations of measured chemicals were within acceptable national and international standards in the samples studied. Only one brand of bottled water had higher than acceptable range fluoride concentration.

Mean, minimum and maximum values of 12 physical and chemical parameters of 30 brands of bottled waters are shown in Table 3. In addition, comparison of measured values with labeled ones of bottle samples is shown in Table 3. The differences between minimum and maximum concentrations for most measured compounds were relatively high. According to paired-samples t-test results, measured concentrations of sodium, calcium, magnesium, fluorides, nitrates, chlorides, pH and total dissolved solids (TDS) differed significantly from those on labels of bottled water produced by manufacturing

companies. On the other hand, no significant difference was observed between measured values of potassium, total hardness, sulfates and nitrates with those on labels of drinking water bottles produced by manufacturing companies.

Table 2

Measured values of physicochemical parameters of bottled drinking water brands

No.	pH	Electrical conductivity [μS/cm]	TDS [mg/dm^3]	Turbidity [NTU]	Alkalinity	Total hardness	TSS	K^+	Na^+	Mg^{2+}	Ca^{2+}	F^-	NO_3^-	SO_4^{2-}	Cl^-
					[mg/dm^3]										
1	7.1	105	53	0	15	20	40	0	4	6	8	0.4	0.3	1	0.1
2		120	53	0	20	40	50	0	15	6	8	0.6	0.4	13	0.1
3		181	90	0	72	70	50	0	15	8	32	1	0.7	19	3.4
4		235	114	0	80	98	57	0	18	8	36	0.1	0.8	19	3.4
5		254	117	0	82	98	66	0	21	9	36	0.2	1.0	20	4.9
6		260	123	0	95	105	66	0	21	9	36	0.2	1.6	21	5.3
7		260	125	0	100	110	67	0	21	10	39	0.2	2	22	7.6
8		266	130	0	110	123	67	0	37	10	40	0.3	2.1	23	10.5
9	7.3	270	134	0	115	132	68	0	47.5	10	42	0.3	2.2	27	23
10		272	134	0	120	135	68	0	54	10	42	0.4	2.6	28	25
11		288	140	0	132	142	73	0	57	12	45	0.5	2.8	28	29
12		341	171	0	145	143	73	0	57.5	12	46	0.5	2.9	29	29
13	7.5	363	181	0	154	156	77	1.4	65	12.5	50	0.5	3	31	36
14		371	185	0	168	167	84	1.4	66	12.5	52	0.5	3	31	42
15		376	187	0	170	170	84	1.4	75	13	52	0.6	3.2	33.5	43
16		410	205	0	170	170	85	1.4	75	13	56	0.2	3.2	36	43
17		410	224	0	173	180	93	1.7	78	14	58	0.2	3.5	44	46
18		447	224	0	180	190	93	1.7	83	14	58	0.2	3.6	53	48
19	7.6	467	233	0	190	190	93	2.4	83	17	59	0.2	3.8	54	65
20		468	233	0	190	197.5	97	2.4	89	17	60	0.2	3.9	56	66
21		473	235	0	198	198	107	2.4	90	22.5	60	0.3	4	59	70
22	7.7	512	250	0	220	200	107	2.6	95	23	64	0.3	4.1	61	74
23		540	250	0	232.5	200	116	2.6	98	23	66	0.3	4.5	68	95
24		541	271	0	234	200	116	2.7	98	24	69	0.4	4.8	73	95
25		565	271	5	240	210	196	2.7	100	24	70	0.5	5.5	76	110
26		575	287	5	245	217.5	226	3	103.5	32	75	0.5	6.4	78	115
27	8.2	656	327	8	247.5	220	229	3.7	110.5	39.5	77	0.5	10.2	116	120
28		686	340	10	250	221	242	3.7	120	39.5	80	0.5	11.6	121	140
29		770	383.5	11	255	270	255	4.8	120	41	95	0.5	22.6	127	175
30		785	394	12	270	285	380	4.8	135	41	100	1.2	25	132	175

Microbiological quality of bottled drinking water (total coliform and heterotrophic plate counts) has also been evaluated. The analysis showed that 93.4% of bottle samples showed no positive coliform results. Two bottle brands displayed positive coliform results while 53% of the samples – positive heterotrophic plate counts (HPC).

Table 3

Measured and labeled concentrations and other parameters of constituents in 30 bottled drinking waters brands

Parameter	Measured value, mg/dm^3			Labeled value, mg/dm^3			*P*-value[a]
	Mean	Min	Max	Mean	min	Max	
Sodium	72.4	15	135	11.9	1	43.5	<0.001
Potassium	1.56	0	4.8	1.33	0.1	6	0.97
Calcium	53.4	8	100	47.1	9.8	78.5	0.002
Magnesium	17.7	6	41	13	0.2	26	0.023
Total hardness	161.9	20	285	173	144	198	0.21
Fluorides	0.43	0.1	1.25	0.29	0	0.8	<0.001
Sulfates	49.9	1	132	33.1	1	120	0.28
Nitrates	4.8	0.3	25	3.1	0.4	9.1	0.036
Nitrites	0.006	0	0.02	0	0	0	0.18
Chlorides	74.1	0.1	251	26.7	0.7	116	0.002
pH	7.50	7.12	8.20	7.32	6.75	7.70	0.001
TDS	233.9	53	394	205.2	130	301	0.016

[a]Paired-Samples *t*-test.

Bottled water of various brands did not have uniform and homogenous physical composition. pH and total hardness were within acceptable range. Nitrite concentration in all samples was close to zero. Discrepancies in parameters reported on labels of bottled water were also observed in studies of other authors [14]. Maqbool and Bajahlan [4] found that mean total hardness if bottled water in Lebanon was 121.8 mg Ca^{2+}/dm^3 and in Saudi Arabia [5] it was 85.7 mg Ca^{2+}/dm^3. This finding is within the acceptable and desired range according to Iranian National Standard. Amounts of total dissolved solids were higher in our study compared to what was obtained in a study conducted in Sri Lanka, [13] in which TDS was from 9 to 123.7 mg/dm^3. TDS determined in our study was also higher than the one obtained in the study conducted by Lucy et al. [4] where mean TDS was equal to 13 mg/dm^3.

In a similar study conducted in Kuwait on drinking bottled water, pH of about 44% of samples was above 8 while about 8% of the samples were relatively acidic (pH lower than 7) [16]. Mean pH of 22 different brands of bottled water in Sri Lanka was 6.2 (acidic) whose range varied from 4.1 to 7.6. In addition, in the former study, maximum concentration of calcium was 253 mg Ca^{2+}/dm^3 in the samples (the same as the case of most samples in this

study) while maximum concentration of nitrate was 4.19 mg NO_3^-/dm^3 (less than samples examined in the present study) [13]. In a research conducted by Ikem et al. in the U.S., pH of none of the samples of bottled water was higher than 8.5 while pH of seven brands of bottled water was lower than 6.5 [17]. Samadi et al. [15] showed that mean pH of water bottles was 8 whose range varied from 7.1 to 8.7. In a study conducted in Turkey, pH of bottled drinking water ranged from 6.3 to 7.1. In addition, calcium concentration was within a range from 16.8 to 179.8 mg Ca^{2+}/dm^3 [18]. In a similar study conducted in Greece, range of pH was from 6 to 8.2 while maximum calcium, sulfates and chlorides concentrations were 486 mg Ca^{2+}/dm^3, 118.7 mg SO_4^{2-}/dm^3 and 100 mg Cl^-/dm^3 [19]. In comparison to this study, calcium concentration in bottled drinking water was higher in Greece [19], while sulfate and chloride concentrations were lower. In the study conducted by Semerjian [4] it was shown that pH for about 12.5% of samples was above the standard pH while 6.3% of the samples had higher hardiness and higher than standard calcium concentration. It is clear that composition of mineral water is influenced by sediment and underground layers involved in circulation of water.

A relatively large difference was observed between minimum and maximum chemical compositions. This finding is in line with those obtained by Yekdeli et al. [20]. This relatively large difference can be attributed to various geological water resources. Chemical composition of natural water is determined by many factors such as chemical precipitation, mineralogy of rocks exposed along the groundwater flow direction, climatic conditions and mapping of the area [21]. If bottled water is exposed to high temperatures and/or sunlight, it can become contaminated by the degradation products of the material from which the bottle was made [22].

In the study conducted by Samadi et al. [10] contents of fluorides, nitrates, chlorides, sodium, sulfates, potassium, TDS, total hardness and calcium concentration had significant differences with labeled values on bottled drinking water. This result was in line with those obtained in this study except in the cases of sulfates and potassium. This shows that agencies monitoring health status such as Ministry of Health, Standards and Industrial Research Institute should plan effective monitoring programs for companies producing bottled drinking water. These programs should periodically review the proposed standard.

A comparison between compositions of bottled waters and maximum acceptable concentration proposed by Iranian National Standards indicated all concentrations of chemical and physical elements listed in Table 1 displayed significant differences with those values proposed by Iranian National Standards. However in the study conducted by Samadi et al. [10] only measured pH and calcium concentration differed from those proposed by Iranian National Standard. In other words, in the present study, all measured values for drinking bottled water were lower than those proposed by the Iranian National Standard, which are within acceptable and appropriate range. It seems that these drinking water bottles do not pose health risks to consumers.

Based on findings of the present study, approximately 6.6% of samples showed positive coliform results while 53% of the samples showed HPC positive results at 37 °C. Semerjian in 2011 [4] found that from 32 brands of bottled water about 18.8% showed positive coliform results while 59.4% of the samples showed positive HPC results. However, it was shown that one brand showed positive fecal coliform results [24]. In a similar study conducted on 25 brands of drinking bottled water in 2011 it was shown that no fecal coliform was found in the samples. However, positive HPC results were observed in two brands of bottled water [9]. Bacteria may be generated in bottled water from a natural source of water or may be introduced during the bottling process [7]. Rapid growth of bacteria prior to bottling water may be due to increased surface area, increased temperature during saving and trace nutrients during storage [23]. According to findings, controlling process of production and performing microbiological quality test for the final product is considerably important. The continually increasing popularity of bottled waters and the conventional wisdom that they are of the highest quality merely serve to underscore the need to carry out further and more detailed studies in this respect [25].

4. CONCLUSIONS

Values of total hardness and pH of bottled water were within acceptable range. Nitrite concentration in all samples was close to zero. Only 6% and 20% of the samples had higher than acceptable values of fluoride and turbidity, respectively. Measured concentrations of sodium, calcium, magnesium, fluorides, nitrates, chlorides, pH and total dissolved solids (TDS) had significant differences with those on labels of sample bottles. On the other hand, two bottle brands showed positive fecal coliforms while 16 brands showed positive HPC results at 37 °C. These two indices indicate presence of pathogenic microorganisms.

ACKNOWLEDGEMENTS

This study was supported by funds (Grant No. 9063) from Vice Chancellor for Research, Shahroud University of Medical Sciences, Iran. The authors thank Mrs. Fatemeh Davardoost for conducting laboratory analyses at the Department of Environmental Health of Shahroud University of Medical Sciences.

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