Environ Monit Assess (2008) 139:277–285
DOI 10.1007/s10661-007-9833-9

An assessment of the quality of various bottled mineral water marketed in Turkey

A. Baba · F. S. Ereeş · Ü. Hıçsönmez · S. Çam · H. G. Özdılek

Received: 28 December 2006 / Accepted: 18 May 2007 / Published online: 19 June 2007

Abstract Fifteen bottled mineral waters purchased at random all over Turkey were analyzed for their chemical composition by OPTIMA-2000 ICP-AES Perkin Elmer techniques. Results show a wide spread in the chemical specification of these mineral waters, with differences in chemical composition observed in the regions being due to the geological environment and the majority of bottled mineral waters exceeding the pH limit of Turkish drinking water standards. When the concentrations of elements are evaluated, it can readily be seen that generally there are three types of mineral water in Turkey. The concentrations of Al, B, Ba, Cd, Cu, Cr, Fe, Mn Pb and Zn in mineral water were compared with the limits established by the Turkish Standard for Natural Mineral Waters (Turkish Official Gazette 2004); water standards prepared by World Health Organization (2006) and the United States of America Environmental Protection Agency (US EPA) drinking water standards (1993). Such a comparison shows that, except for Ba and Mn, the concentrations of the other heavy metals are lower than the limit of the US.EPA in Turkey. Some parameters examined were found to comprise strong correlations pair-wise.

Keywords Mineral water · Trace elements · Drinking water · ICP-AES · Turkey

A. Baba (✉) · H. G. Özdılek
Engineering and Architecture Faculty,
Geological Engineering Department,
Canakkale Onsekiz Mart University,
Terzioglu Campus,
17020 Canakkale, Turkey
e-mail: alperbaba@comu.edu.tr

F. S. Ereeş · S. Çam
Sciences and Arts Faculty, Physics Department,
Celal Bayar University,
Muradiye, Manisa, Turkey

Ü. Hıçsönmez
Sciences and Arts Faculty, Chemistry Department,
Celal Bayar University,
Muradiye, Manisa, Turkey

Introduction

Without water, there would be no animal and plant life, at least, not the way we know it. The water consumed by human beings comes in various forms and from various sources. Recently, the popularity of bottled mineral water with consumers has increased dramatically due to the ever-increasing contamination of water resources. Mineral water always contains various minerals and trace elements (Hem 1978; Deutsch 1997), and can be defined as water containing minerals which are natural compounds formed through geological processes or other dissolved substances that alter its taste or give it therapeutic properties; alternatively, it is the act of remediation of a health problem after diagnosis. Minerals are required by human beings for nutrition, growth, sustaining body functions and well-being. However, types and concentrations of minerals depend highly upon various factors. Malini et al. (2003) postulated that rock-water interaction is the most important phenomenon determining groundwater quality around Mysore, Karnataka, India. Salts, sulphur compounds, and other compounds are among the substances that can be dissolved in the water. These minerals have various effects on the health of a person (Burton and Cornhill 1977; Burton et. al. 1980; Epstein and Zavon 1974). Pure water is probably the most important resource on earth. This was recognized in 600 BC by Thales of Milet. However, what is pure water; only H_2O? Any natural material on earth, even ‘pure’ water, contains all the elements tabulated in the Periodic Table – at least in traces (Misund et al. 1999).

Natural concentrations in water from different parts of the world have recently been documented by Reimann and de Caritat (1998). Reported natural concentrations for many elements span several orders of magnitude due to the sources’ geological background, landforms and use of land (Kara et al. 2004; Panapitikkul et al. 2005), and anthropogenic activities (Nkhuwa 2003; Buor 2004; Chapelle 2003). Mineral water is actually based on a minimum concentration of dissolved salts. In judging drinking water quality, bacteriology has traditionally played a more important role than chemical composition (Misund et al. 1999) but the world has seen many cases of serious chemical contamination in drinking water highlighted in newspapers and scholarly written articles over the last 20 years. Despite the fact that many Western European nations enjoy a percentage compliance rate in the high 90s for their tap water, the mineral water industry has been very successful in marketing mineral waters as ‘better drinking water.’ Yet, in the United States, for example, the proportion of waterborne disease outbreaks linked with problems in public water distribution systems has been noted to be on the increase (Lee et al. 2002; Blackburn et al. 2004). Such examples convince the public to use bottled water. This is reflected in ever-increasing sales figures (Samek 2004) since mineral water totaling many billion dollars is sold each year on a worldwide scale (Misund et al. 1999).

Natural mineral water is characterized by its mineral content, trace elements or other constituents and, where appropriate, by certain effects; also, by being in its original state; both conditions having been preserved intact because of the underground origin of the water which has been protected from all risk of pollution. The composition, temperature and other essential characteristics of natural mineral water must remain stable at source within the limits of natural fluctuation; in particular, they must not be affected by possible variations in the rate of flow. Mineral waters may be gaseous or non-gaseous. In terms of treatment, disinfections are not allowed. Filtration or decanting and the addition or removal of carbon dioxide is the only treatment authorized (Misund et al. 1999).

It is generally recognized that in addition to the major elements, e.g. Ca, K, Mg, Na, P, and S, there are a number of elements, e.g. Co, Cr, Cu, Fe, I, Mn, Mo, Se, V, and Zn that are essential for many life functions (Edmunds and Smedley 1996). Drinking water is an important source for the daily intake of many of these elements. Trace elements are present in living organisms at very low levels but some of them play a key role in many different biochemical reactions that occur in the human body. A number of such elements are found in natural mineral waters. Iron and fluorine are probably the most widely-known, for their capacities to protect against anemia and dental caries, respectively. Additionally, other important trace elements include iodine, zinc, molybdenum, selenium, copper, and strontium.

Up to now, there has been much debate about the health-giving effects of mineral water. Apart from the obvious function of providing liquid to the body, there are no scientific studies that actually show a significant beneficial effect of mineral water on the health. While mineral water clearly contains minerals that are, in principle, beneficial for the body, the ability of the body to absorb them from mineral water is not exactly proven. But since natural water is free of any calories, sugar or artificial ingredients, it is certainly better than a sweetened, flavored soft drink. There usually being no adverse effects from drinking mineral water, you may therefore drink it just for its fresh taste.

The aim of this study is to determine the quality of mineral waters in different parts of Turkey. A total of 15 bottled mineral water samples collected from nine different Turkish provinces were analyzed for 30 variables in order to compare their ingredients with existing national and international standards.

Material and methods

During 2003, 15 bottles of mineral water were bought in randomly selected shops situated in different parts of Turkey. Figure 1 shows the locations where the samples were purchased. Analysis given by the American Public Health Association (APHA 1992) was followed to obtain the specification of the water samples. The collected water samples were divided into two groups: (1) heavy metal ions, and (2) major ions.

The pH of water samples for heavy metals was adjusted to pH 2 by adding lab grade nitric acid (HNO_3). All analyses for heavy metals were completed within a week. All samples were stored in refrigerated conditions prior to completing related analyses at Celal Bayar University, Manisa, Turkey. A 100-ml sample of mineral water was used for determination of the selected variables. The elements such as Na, Mg, Al, B, Co, Ca, Ba, Cu, Mn, Ni, Zn, Cr, Cd, Sn, Ti, Fe, Sr, Sb, Pb, Bi, U, Zr, La, K and Si were read by the inductively coupled plasma atomic emission spectrometry ICP-AES (OPTIMA-2000 Perkin Elmer) technique. A regression line was produced using five different standards prior to analyses of the samples concerned. At least 99.5% regression coefficient was achieved prior to readings. Three replicates were read for each sample analyzed and their mean value was taken into account for assessment.

The $SO_4^{=}$, Cl^{-}, HCO_3^{-}, pH and electrical conductivity of each sample was also measured at the laboratory (Table 1). Ionic strength was computed using major ion concentrations expressed as molalities. Fundamental statistical specifications of the samples obtained were evaluated using SPSS (Statistical Package for Social Sciences) 10.0 program (Table 2).

Fig. 1 Location map of study area

Results and discussion

Table 1 summarizes the analytical results for the mineral water samples. As a general principle, mineral water is defined as gaseous or non-gaseous water that includes at least 1 g of dissolved mineral and/or trace element in 1 l volume and arises under natural geological conditions. According to this principle, sample 1 (coded as 01İ) was found to include slightly more than 440 mg l^{-1} of mineral compounds and trace elements. Based on a directive definition, mineral waters that include less than 500 mg minerals are categorized as having low mineral substance (Turkish Official Gazette 2004). Moreover, sample 10 (coded as 10E) has approximately 926 mg total mineral and element content in 1 l of water. Thus, both the 01İ and 10E samples should be regarded as low mineralized bottled water compared to the rest of the samples studied. On the other hand, the samples coded 06K, 07K and 08K include more than 3,300 mg total mineral and trace element concentrations in each liter of water sample. By definition, mineral water that contains more than 1,500 mg minerals and elements is termed "rich" mineral water (Turkish Official Gazette 2004). Based on this classification, only the 01İ, 04S and 10E samples were not found to be rich in terms of their mineral content. However, the majority of samples analyzed (80%) are significantly richer when we examine the minerals and trace elements listed in Table 1.

HCO_3^{-} is the predominant constituent of all water samples examined for this study. It was found to be correlated with pH (0.587 (significant at 0.021)); electrical conductance (0.90 (significant at 0.000)); K (0.696 (significant at 0.004)); Na (0.803 (significant at 0.000)) and B (0.661 (significant at 0.007)) based on statistical analysis.

Although no regulatory or guideline value was established for pH in the Turkish natural mineral water directive, all mineral water samples examined for this study, with the exception of water sample coded 05A, were found to be remarkably acidic based on Turkish drinking water standards. The pH was determined to have an inverse correlation with Sn

Table 1 Chemical composition of mineral water in Turkey

Location	Sample Code	PH	EC µS/cm	$SO_4^=$ (ppm)	HCO_3^- (ppm)	Cl^- (ppm)	K^+ (ppm)	Si (ppm)	Na^+ (ppm)	Mg^{++} (ppm)	Water-type
Giresun	01İ	5.50	534	40.01	251.14	8.15	2.54	12.33	9.91	15.09	CaMg-HCO_3
Manisa	02S	6.25	1690	289.00	1141.02	25.27	12.07	14.52	37.65	46.26	Ca-HCO_3
Bursa	03Ö	5.92	1333	25.01	1450.04	90.04	16.11	13.02	64.60	77.29	CaMg-HCO_3
Manisa	04S	5.68	962	119.02	714.13	30.24	10.13	11.34	64.97	50.62	CaMgNa-HCO_3
Bolu	05A	6.73	1347	5.05	1403.25	7.05	7.98	7.33	38.90	28.59	Ca-HCO_3
Bursa	06K	6.20	3920	88.02	2940.27	43.12	77.50	17.47	1200.10	88.91	NaCa-HCO_3
Ankara	07K	6.02	2330	110.03	2325.12	532.06	77.95	17.95	449.20	17.23	NaCa-HCO_3
Afyon	08K	6.16	3350	25.05	2374.17	109.11	16.76	34.96	735.70	12.49	Na-HCO_3
Bursa	09U	5.82	1725	8.04	1154.19	80.35	42.99	17.77	150.70	62.88	CaNaMg-HCO_3
Denizli	10E	5.65	925	32.05	488.07	188.42	17.68	12.22	21.07	46.93	CaMg-HCO_3
Bursa	11S	6.22	3120	30.00	2196.13	202.47	65.20	15.99	99.43	2.37	Ca-HCO_3
Manisa	12K	6.20	3280	23.12	2013.04	91.36	66.24	25.13	439.90	97.86	NaCa-HCO_3
Balýkesir	13K	5.97	2010	135.14	1452.11	64.15	41.14	26.46	173.90	29.04	CaNa-HCO_3
Mugla	14G	6.11	2420	174.21	1610.13	41.00	44.14	35.30	197.40	39.64	CaNa-HCO_3
Ankara	15B	6.01	2910	147.12	1415.31	20.02	70.20	46.59	275.50	137.70	NaCaMg-HCO_3
Turkish standards, Turkish Official Gazette 2004		6.5–8.5	2500	250		250			200		
WHO standards 2006											
US EPA 1993				250		250					

Location	Sample Code	Al (ppb)	B (ppb)	Co (ppb)	Ca (ppm)	Ba (ppb)	Cu (ppb)	Mn (ppb)	Ni (ppb)	Zn (ppb)	Cr (ppb)	Cd (ppb)
Giresun	01 İ	6	8	8	102.90	<1	<1	29	<1	<1	<1	<1
Manisa	02S	10	13	9	361.80	52	<1	249	<1	<1	12	1
Bursa	03Ö	16	158	9	119.90	158	<1	101	<1	<1	2	<1
Manisa	04S	12	169	8	81.11	43	<1	12	<1	<1	11	<1
Bolu	05A	<1	29	7	305.20	192	<1	<1	<1	<1	<1	<1
Bursa	06K	12	365	10	247.20	61	<1	180	<1	<1	10	<1
Ankara	07K	11	435	8	109.30	121	20	17	<1	95	4	4
Afyon	08K	15	616	8	39.08	<1	<1	69	<1	13	1	<1
Bursa	09U	<1	<1	10	183.10	226	2	152	8	5	2	<1
Denizli	10E	45	6	8	118.60	53	<1	<1	<1	<1	13	<1
Bursa	11S	<1	<1	8	305.50	820	<1	<1	<1	6	7	<1
Manisa	12K	16	173	8	248.90	249	138	90	420	62	9	<1
Balýkesir	13K	8	196	11	126.20	33	2	1150	<1	22	1	<1
Mugla	14G	20	58	8	420.80	76	<1	198	<1	1	11	<1
Ankara	15B	11	116	8	172.00	76	41	485	<1	24	<1	<1
Turkish Standards 2004		200	1000			1000	1000	500	20		50	3
WHO Standards 2006		100	5000			700	2000	400	70			
US EPA 1993		200	1000		200	100	1000	50		5000		5

Location	Sample Code	Sn (ppm)	Ti (ppb)	Fe (ppb)	Sr (ppm)	Sb (ppb)	Pb (ppb)	Bi (ppb)	U (ppb)	Zr (ppb)	La (ppb)
Giresun	01İ	0.236	1	1	0.230	<1	<1	12	1	3	<1
Manisa	02S	0.218	7	5	0.901	<1	<1	9	1	4	<1
Bursa	03Ö	0.225	5	2	0.489	<1	<1	9	4	5	<1
Manisa	04S	0.205	4	11	0.214	<1	<1	22	5	4	<1
Bolu	05A	0.070	3	<1	0.638	<1	<1	7	<1	<1	<1
Bursa	06K	0.244	6	<1	0.710	<1	<1	17	<1	<1	<1
Ankara	07K	0.230	6	6	0.720	<1	<1	9	6	4	<1
Afyon	08K	0.238	20	6	0.132	<1	<1	20	8	5	<1
Bursa	09U	0.167	31	8	0.726	<1	<1	22	2	4	<1
Denizli	10E	0.205	12	1	0.434	<1	<1	25	92	2	<1

Table 1 (continued)

Location	Sample Code	Sn (ppm)	Ti (ppb)	Fe (ppb)	Sr (ppm)	Sb (ppb)	Pb (ppb)	Bi (ppb)	U (ppb)	Zr (ppb)	La (ppb)
Bursa	11S	0.147	30	13	0.730	<1	<1	17	<1	4	<1
Manisa	12K	0.160	64	17	0.730	<1	1	21	1	3	<1
Balýkesir	13K	0.209	9	<1	0.827	<1	<1	9	5	4	<1
Mugla	14G	0.260	6	<1	0.760	<1	<1	18	5	4	<1
Ankara	15B	0.190	4	11	0.750	<1	<1	21	3	7	<1
Turkish Standards 2004			200			10		15			
WHO standards 2006						10					
US EPA 1993			300			15					

(−0.520 (significant at 0.047)); yet, positive correlation with Ca (0.599 (significant at 0.018)). The pH limitation based on water quality standards used for currently operated or intended for water supply services is 6.5 and 8.5 (Turkish Official Gazette 2005).

One third of the samples assessed were found to surpass the electrical conductivity limit value determined by the Turkish Mineral Water Regulation (Turkish Official Gazette 2004). Electrical conductivity was found to be correlated with K (0.761 (significant at 0.000)); Si (0.572 (significant at 0.026)); Na (0.79 (significant at 0.000)); and B (0.536 (significant at 0.039)).

Differences based on the electrical conductivity of the samples collected exist even within the same province, such as between 02S and 04S (Manisa); 03Ö, 09U and 06K, 11S (Bursa); 07K and 15B (Ankara). Only one $SO_4^=$ value (sample 04S) was found to be greater than that of the regulatory limit set for Turkish drinking water standards. Therefore, it is difficult to confirm that Turkish mineral waters contain excessive $SO_4^=$. No regulatory limits exist for HCO_3^-, K, Si and Mg in Turkey (Turkish Official Gazette 2004).

Only one sample (07K), collected from the country's capital Ankara, was found to exceed the chloride level limit regulated by Turkish drinking water standards. Furthermore, the same sample, along with 06K, 08K, 12K and 15B collected from Bursa, Afyon, Manisa and Ankara, have high sodium concentrations, possibly due to the facility site and not provincial, geological specifications. Unfortunately, we did not have sufficient information about the geological setting of the different springs supplying the water collected to satisfactorily explain this break. The main message obtained is that the data set is inhomogeneous, probably caused by significant differences in the overall composition of waters from different geological settings.

For some of the elements analyzed, some samples returned values below the respective detection limits. For a number of elements (Cd, Cu, La, Ni, Pb, Sb and Zn), most values were found to be below the detection level.

The chemical characteristics of the mineral water composition, on the basis of major ion concentrations, were evaluated on a Piper diagram (Fig. 2). When the concentrations of the elements are evaluated, it can readily be seen that there are three types of mineral water in Turkey. First, water that is relatively rich in Ca–HCO_3 (calcium-bicarbonate type), which can be seen in Bursa, Bolu, Denizli, Giresun and Manisa. In the second, the water is relatively rich in CaNa–HCO_3 (calcium–sodium-bicarbonate type), which can be seen in Balikesir, Bursa and Mugla. The third type of water is relatively rich in Na–HCO_3 (sodium-bicarbonate type), which can be seen Ankara, Afyon, Bursa, Bolu and Manisa. The mineral waters revealed that they have an ionic strength value between 0.0105 and 0.0745, averaging 0.037, despite the fact that the ionic strength values were not tabulated.

No regulatory limits were established by Turkish drinking water directive for Ca, Ba, Bi, Co, K, La, Mg, Si, Sn, Sr, Sb, Ti, Zn and Zr. Results showed that 40% of the samples assessed were determined to have an excessive level of calcium based on the US EPA regulation. Similarly, 40% of the samples were found to have high barium levels according to the upper limit noted by the US EPA, in spite of the fact

Table 2 Fundamental statistical parameters of mineral water in Turkey

Variable	Statistical property							
	Minimum	Maximum	Range	Mean	Standard error	Variance	Skewness	Kurtosis
PH	5.5	6.7	1.23	6.03	0.076	0.0903	0.359	1.126
EC	534	3,920	3,386	2124	265	1,050,771	0.174	−1.089
$SO_4^{=}$	5.05	289	284	83.4	20.6	6,349	1.305	1.699
HCO_3^{-}	251	2,940	2,686	1,529	192	552,722	0.094	−0.368
Cl^-	7.05	532	525	102	34.3	17678	2.718	8.397
K^+	2.54	77.9	75.4	37.9	7.16	768	0.254	−1.661
Si	7.33	46.6	39.3	20.6	2.84	121	1.182	0.763
Na^+	9.91	1,200	1,190	264	85.1	108677	1.980	4.016
Mg^{++}	2.37	138	135	50.2	9.61	1386	0.951	0.636
Al	0.001	0.045	0.044	0.012	0.003	0.0001	2.046	6.112
B	0.001	0.62	0.62	0.156	0.048	0.0339	1.420	1.524
Co	0.007	0.011	0.003	0.009	0.0003	1.1×10^{-6}	1.145	0.810
Ca	39.1	421	382	196	29.2	12769	0.609	−0.661
Ba	0.001	0.82	0.82	0.144	0.052	0.041	2.973	9.967
Cu	0.001	0.14	0.14	0.014	0.009	0.0013	3.346	11.70
Mn	0.001	1.15	1.15	0.182	0.077	0.089	2.815	8.708
Ni	0.001	0.42	0.42	0.029	0.028	0.012	3.871	14.99
Zn	0.001	0.10	0.009	0.016	0.007	0.0007	2.301	4.972
Cr	0.001	0.010	0.009	0.006	0.001	2.3×10^{-5}	0.298	−1.84
Cd	0.001	0.004	0.003	0.001	0.0002	6×10^{-7}	3.873	15.0
Sn	0.07	0.26	0.19	0.20	0.012	0.0023	−1.472	2.679
Ti	0.001	0.064	0.063	0.014	0.004	0.0003	2.242	5.408
Fe	0.001	0.017	0.016	0.006	0.0014	2.8×10^{-5}	0.847	−0.35
Sr	0.132	0.901	0.769	0.599	0.062	0.058	−0.938	−0.421
Bi	0.007	0.025	0.018	0.016	0.0016	3.7×10^{-5}	−0.173	−1.617
U	0.001	0.092	0.091	0.009	6×10^{-3}	5.3×10^{-4}	3.809	14.65
Zr	0.001	0.007	0.006	0.004	4×10^{-4}	2.4×10^{-6}	−0.025	0.866

that the World Health Organization (WHO) value for barium is considerably higher than that of US EPA. In addition to the WHO guidelines (2006), the Codex Alimentarius Commission (1997) guideline values were also used for comparison. Therefore, only one sample (coded 11S) was determined to have excessive barium according to the WHO standards (WHO 2006); whereas all examined samples are below the Codex Alimentarius Commission guide value, which is 1 mg l^{-1} (Codex Alimentarius Commission 1997). For nickel, it was observed that just one mineral water sample examined was found to have more than 20 times more nickel based on standards for both Turkish drinking water (Turkish Official Gazette 2005) and Turkish natural mineral water regulations (Turkish Official Gazette 2004). Only one sample (13K) has higher manganese than the allowable value based on Turkish standards (Turkish Official Gazette 2004), whereas even this sample includes less manganese than the allowable upper limit based on the guide (2 mg l^{-1}) provided by the Codex Alimentarius Commission (1997). The sample coded 10E obtained from Denizli, where the world-famous white travertine site (Pamukkale) is also situated, showed an elevated uranium concentration.

The concentrations of Al, B, Ba, Cd, Cu, Cr, Fe, Pb, Mn and Zn in mineral water can be compared with the limits established by the US Environmental Protection Agency (US EPA 1993) (Table 1). Such a comparison shows that the concentrations of Ba in the samples collected in Bursa and Manisa are higher than the US. EPA limits. Also, the concentration of Mn in all samples is higher than the US EPA limits; however, the concentrations of the other heavy metals are lower in Turkey than the limit of the EPA. Only one sample examined (07K) has a moderately elevated cadmium concentration compared to Turkish mineral water regulations (Turkish Official Gazette 2004) and the

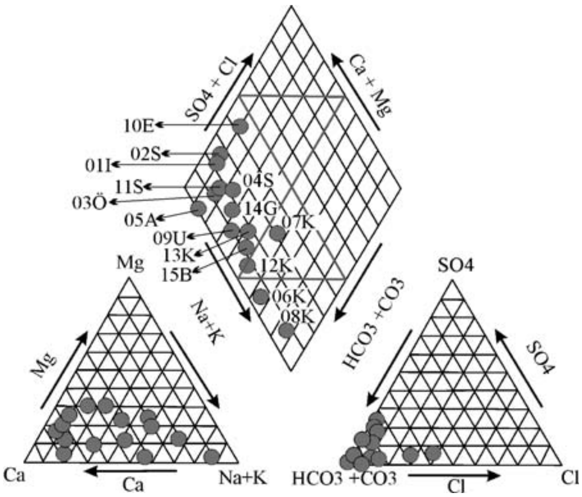

Fig. 2 Piper Diagram showing the major ionic composition of the sampled mineral water

guideline value of 3 μg l^{-1} prepared by the Codex Alimentarius Commission (1997). It should be stated that the concentrations of heavy metals are generally not high in all the samples. With the exception of one mineral water, coded 05A, the pHs of water samples are not within the allowable range.

Notable correlations between Cl and Zn and Cl and Cd pairs exist as 0.737 (significant at 0.002) and 0.894 (significant at 0.000) respectively. K was determined to be well correlated with Na (0.551 (significant at 0.033)); Zn (0.584 (significant at 0.022)); and Sr (0.58 (significant at 0.024)). Si was found to be only correlated with Zn (0.649 (significant at 0.009)). Similarly, Na has a correlation with only one variable (B) (0.758 (significant at 0.001)). Cu is correlated with Ni, Zn, Ti and Fe as 0.951 (significant at 0.000), 0.594 (significant at 0.020), 0.752 (significant at 0.001), and 0.666 (significant at 0.007), respectively. Al has correlations with Cr (0.537 (significant at 0.039)) and U (0.864 (significant at 0.000)). Co was found only to be correlated with Mn (0.68 (significant at 0.005)). As expected, Sr was found to be correlated with Ca (0.679 (significant at 0.005)). Interestingly, the only inverse correlation was established between Ba and Fe (−0.515 (significant at 0.05)). Significant correlations between Ni and Sr and Ni and Fe were determined as 0.834 (significant at 0.000) and 0.597 (significant at 0.019) respectively. Finally, Ti was found to be very well correlated with Zn and Fe as 0.802 (significant at 0.000) and 0.707 (significant at 0.003).

A total of five groups were identified based on cluster analysis (Fig. 3). The 06K and 07K samples are different from all other groups. These two samples have the highest K concentrations compared to the other samples analyzed. Furthermore, the highest Cl^- concentration was found to belong to the 07K sample. The Na level of the same sample is close to the Cl^- concentration. The 06K sample has the most elevated $HCO_3^=$ level among all samples; whereas there is an unbalanced ratio between Na^+ and Cl^-. The samples coded as 08K, 11S, 12K, 14G and 15B were determined to have close specifications based on all variables examined. These samples are all belong to different provinces. Mineral water samples coded 01İ, 04S and 10E show similar characteristics. All three samples have less than 720 mg l^{-1} $HCO_3^=$ concentrations. Another group, which is the largest, consists of the samples coded 02S, 03Ö, 05A, 09U and 13K. Mineral water samples, even if collected from the same province, showed various specifications based on examined variables. Hence, a province-wide generalization about spring water quality cannot be made in Turkey. Site-specific features should be always kept in mind.

Mineral water is so essential that a person's standard of living in Turkey is believed to be raised with the increased consumption of mineral water. Furthermore, increase in mineral water consumption often signifies development in a country. Yet, combustion of fossil fuels in dwellings, industrial plants, electric generation plants and vehicles causes an increase in the nitrogen and sulfur in the atmosphere. After the formation of oxides of nitrogen and sulfur in the atmosphere, sulfuric and nitric acids (the final

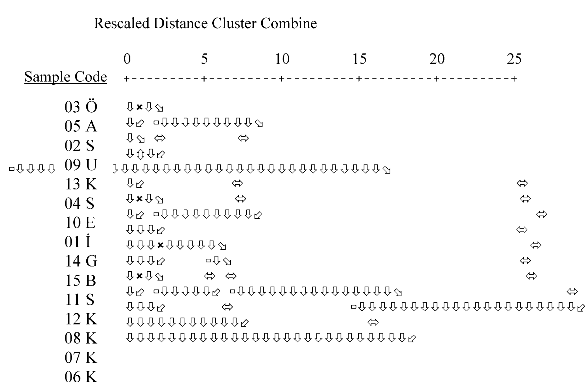

Fig. 3 Hierarchical cluster analysis based on average linkage between samples

product of nitrogen and sulfur) in precipitation can affect certain stream and groundwater resources. Therefore, mineral water resources that are near urban and industrial centers or thermal power plants could be impacted seriously. People who consume impaired mineral waters may adversely be affected depending upon the water's specifications and quantity. In order to assess epidemiological risk due to consumption of low quality mineral waters, the consumer profile and market share of impaired mineral waters should be taken account together. Although it is not our aim in this research to relate mineral water quality and public health, it is highly recommended that public health specialists study this relationship scientifically.

Conclusions

Many people now prefer bottled water to tap water for a number of reasons. They may not like the taste, smell, or color of tap water. Others are worried about their health and see bottled water as more natural, pure, and a healthier alternative to tap water. Therefore, ever-increasing demand for bottled water is a fact all around the globe (Samek 2004). On the other hand, not all bottled waters have the same qualities. Analysis of 15 bottled mineral waters in Turkey for 28 elements shows a wide spread in composition for most of these elements due to geological variances in the water sources.

The natural concentration of a number of elements known to be extremely toxic, for which not even a maximum allowable concentration level for drinking water has been set by the US. EPA, can reach surprisingly high levels. At present, these insufficient action levels for drinking water do not apply to mineral water because it comes, by definition, from a protected source. Generally, mineral water is good for drinking in Turkey. However, all mineral water in Turkey needs to be analyzed regularly. Indeed, it is a requirement that a tri-monthly analysis be carried out on the chemical and bacteriological water quality of all mineral water, generally at Turkish Ministry of Health laboratory facility in Ankara.

Acknowledgement We thank Ibrahim Aksu who checked language of this paper and made very valuable corrections.

References

APHA (1992). Standard methods for the examination of water and wastewater. In A. E. Greenberg, L. S. Clesceri, & A. D. Eaton (Eds.), *U.S. American Public Health Association, American Water Works Association and Water Pollution Control Federation, 18th ed*. (pp. 1–13). Washington, DC.

Blackburn, B. G., Craun, G. F., Yoder, J. S., Hill, V., Calderon, R. L., Chen, N., et al. (2004). Surveillance for waterborne-disease outbreaks associated with drinking water—United States, 2001–2002. *MMWR, 53*(SS-8), 23–45.

Buor, D. (2004). Water needs and women's health in the Kumasi metropolitan area, Ghana. *Health and Place, 10*, 85–103.

Burton, A. C., & Cornhill, F. (1977). Correlation of cancer death rates with altitude and with the quality of water supply of 100 largest cities in the United States. *Journal of Toxicology and Environmental Health, 3*, 465–478.

Burton, A. C., Cornhill, J. F. & Canham, B. (1980). Protection from cancer by 'Silica' in the water supply of U. S. cities. *Journal of Environmental Pathology and Toxicology, 4*, 31–40

Chapelle, F. H. (2003). Geochemistry of groundwater. In H. D., Holland & K. K., Turekian (Eds.), *Treatise on geochemistry*, vol. 5, pp. 425–449. Elsevier.

Codex Alimentarius Commission (1997). Standard for natural mineral waters. Rome, Food and Agriculture Organization of the United Nations and World Health Organization (CODEX STAN 108). Available at ftp://ftp.fao.org/codex/standard/en/CXS_108e.pdf.

Deutsch, W. J. (1997). *Groundwater geochemistry, fundamentals and applications to contamination*. Boca Raton: Lewis, p. 221.

Edmunds, W. M. & Smedley, P. L. (1996). Groundwater chemistry and health: an overview. In J. D. Appleton, R. Fuge, G. I. H. McCall (Eds.), *Environmental geochemistry and health*. Geological Society Special Publication, 113, 91–105.

Epstein, S. S., & Zavon, M. (1974). Is there a threshold for cancer? In D. X. Manners (Ed.), *Water, Its Effects on Life Quality, International Water Quality Symposium* (pp. 54–62). Washington, D. C.: Water Quality Research Council.

Hem, J. D. (1978). *Study and interpretation of the chemical characteristics of natural water, US Geological Survey, 2nd edition*. Washington: US Government Printing Office, p. 362.

Kara, E., Özdilek, H. G., & Kara, E. E. (2004). An investigation on physical, chemical, and bacteriological quality of municipally supplied and well waters of the towns and city centre in the province of Niðde, Turkey. *International Journal of Environmental Health Research, 14*(2), 151–156.

Lee, S. H., Levy, D. A., Craun, G. F., Beach, M. J., & Calderon, R. L. (2002). Surveillance for waterborne-disease outbreaks in the United States, 1999–2000. *MMWR, 51*(SS-8), 1–49

Malini, S., Nagaiah, N., Paramesh, L., Venkataramaiah, P., & Balasubramanian, A. (2003). Groundwater quality around Mysore, Karnataka, India. *International Journal of Environmental Studies, 60*, 87–98.

Misund, A., Frengstad, B., Siewers, U., & Reimann, C. (1999). Variation of 66 elements in European bottled mineral waters. *The Science of the Total Environment, 243–244*, 21–41.

Nkhuwa, D. C. W. (2003). Human activities and threats of chronic epidemics in a fragile geologic environment. *Physics and Chemistry of the Earth, 28*, 1139–1145.

Panapitikkul, N., Pengnoo, A., Siriwong, C., & Chatupote, W. (2005). Hydrogeomorphological controls on groundwater quality in the Rattaphum catchment (Songkhla Lake basin), Thailand. *Water, Air and Soil Pollution: Focus, 5*, 149–163.

Reimann, C., & de Caritat, P. (1998). *Chemical elements in the environment-factsheets for the geochemist and environmental scientist*. Berlin-Heidelberg-New York: Springer, p. 398.

Samek, K. (2004). Unknown quantity: The bottled water industry and Florida's springs. *Journal of Land Use. 19* (2) Spring 569–595.

Turkish Official Gazette (2004). *Directive on natural mineral waters*. December 1, 2004 No: 25657.

Turkish Official Gazette (2005). *Directive on environmental quality of surface water resources that are currently under operation or planned to be used in the future*. November 11, 2005 No: 25999.

US EPA (1993). *Standard methods for the examination of water and wastewater, Environmental Protection Agency (EPA)*. US: American Publish Health Association.

WHO (2006). *Guidelines for drinking-water quality*. First Addendum to Third Edition. Volume 1, Recommendations. Geneva, Switzerland: WHO, pp. 595.