Trace Element Analysis of Water with Inductively Coupled Plasma-Mass Spectrometry

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Abstract

Trace element analysis of the drinking water in the area of St. John's, Newfoundland, Canada has been investigated by an Agilent 7700X inductively coupled plasma-mass spectrometry (ICP-MS). The results indicate that the levels of all measured elements are well below the guidelines of drinking water recommended by the World Health Organization (WHO) and US Environmental Protection Agency (USEPA).

Keywords: water quality, inductively coupled plasma-mass spectrometry

Introduction

Surface water is essential for the daily activity of human being. Hence, it is in particularly important to preserve this precious natural resource to achieve sustainable development of the society. Water analysis is crucial for any specific use of water, such as drinking water, in order to evaluate its suitability as well as removal of any detrimental composition. On the other hand, water analysis is also very important to understand the source and formation of the water in order to reveal natural phenomena and to prevent pollution resulted from human activities. For the case of drinking water, its trace element content is one of the most important characters for water quality. Some trace elements, such as Co, Cr, Cu, Fe, Mn, Mo, Se, and Zn are essential to our health, but when the concentrations exceed the cut-off levels, they can be toxic too; while some other elements are potentially toxic, like Ag, Al, As, Cd, Pb, and Ni. Essential or non-essential elements, when present at elevated levels can cause morphological abnormalities, reduced growth, increased mortality and mutagenic effects in humans (Pier, 1980). To avoid potential hazard caused by elevated concentrations of trace elements in drinking water, international standards have been set by WHO (WHO, 2004) and US EPA (EPA, 2003).
Recently, an increasing worldwide concern about the quality of bottled water and drinking water regarding their chemical contents has become very serious (Soupioni, 2006; Batarseh, 2006; Raj, 2006; Momani, 2006; Saleh, 2001). Determination of trace elements in drinking water requires a method where low levels of detection can be achieved. Inductively coupled plasma-mass spectrometry (ICP-MS) is particularly powerful in the composition analysis for its capability of rapid multi-element analysis in combination with excellent detection limits (Gary, 1975; Houk, 1980; Vanhaecke, 1993; Moens, 1994; Rodushkin, 1997; Riondato, 1997).

This research has been carried out to provide an insight into the levels of trace elements in bottled spring water, bottled demineralized water, bottled remineralized water, tap water and iceberg water present in St. John's, Newfoundland, Canada. In this paper, the results of concentration levels of 19 trace elements in these water samples are presented.

Materials and Methods

Sample Preparation

Six bottled-water samples from reputed brands were purchased from the different supermarket stores in St. John's, Newfoundland, Canada. One tap water sample was collected from a tap of the laboratory at Memorial University after 10 minutes of flushing. The iceberg water from the drift iceberg from western Greenland (Denmark) was collected in Pouch Cove, Newfoundland. Table 1 illustrates the classification of water samples. The water samples were acidified with high purity concentrated HNO_3 to pH 2, and then stored at 4 ℃ until the time of analysis.

Table 1. Classification of water samples

Brand code	Type of water	Origin
B-1	Spring water	Ontario, Canada
B-2	Spring water	Nova Scotia, Canada
B-3	Spring water	Quebec, Canada
B-4	Spring Water	French Alps, France
B-5	Demineralized treated water	Public water sources
B-6	Remineralized water	Ontario, Canada
T-1	Tap water	St. John's, NL, Canada
I-1	Iceberg water	Western Greenland, Denmark

Reagents

All chemicals and reagents used in this study were of ultra-high purity analytical grade from VWR (Radnor, PA, USA). Standard reference materials were purchased from High-Purity Standards (Charleston, SC, USA). Deionized water and the reagent grade water (ASTM Type I water) were prepared from Nanopure Diamond™ Barnstead water purification system (Lake Balboa, CA, USA).

Inductively coupled plasma mass spectrometry (ICP-MS)

All samples were analysed by using an Agilent 7700X ICP-MS equipped with an auto sampler and shield torch octopole reaction system (ORS) which were operated in no gas mode. 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 five standard solutions of all 20 monitored elements except Se were used at concentrations of 0, 0.1, 1, 10, 100, 1000 (µg/L (ppb)), while the concentrations of Se are 5 times higher than all other elements.

Results and Discussion

19 trace elements were analyzed by ICP-MS and the results are listed in Table 2. The WHO guidelines, and the USEPA drinking water standards were listed in Table 3.

Table 2. Levels of trace metals in water samples (μg/L or ppb)

Brand Code	Be	Al	V	Cr	Mn	Co	Ni	Cu	Zn	As
B-1	0.021	0.322	0.062	0.045	0.351	0.024	1.878	0.328	1.285	0.279
B-2	0.011	0.567	3.284	2.759	BDL	0.043	0.770	0.011	BDL	4.680
B-3	0.007	0.045	0.264	0.002	BDL	BDL	BDL	0.062	BDL	1.898
B-4	0.003	BDL	0.140	0.156	BDL	BDL	BDL	BDL	BDL	0.386
B-5	0.019	0.289	0.001	0.003	0.676	0.244	1.177	BDL	BDL	BDL
B-6	0.005	0.138	0.002	0.159	BDL	BDL	BDL	0.076	BDL	0
T-1	0.014	49.507	0.193	0.043	5.897	BDL	0.884	259.047	59.462	0.126
I-1	0.002	1.997	0.865	0.002	0.041	BDL	0.057	1.254	2.004	0.002

Brand Code	Se	Ag	Cd	Sb	Ba	Tl	Pb	Th	U
B-1	0.121	0.003	BDL	0.371	121.286	0.021	BDL	0.002	1.745
B-2	0.160	BDL	BDL	0.146	7.720	0.007	BDL	BDL	0.183
B-3	BDL	BDL	BDL	0.323	1.775	0.004	BDL	0	0.482
B-4	0.169	BDL	BDL	0.521	115.370	0.004	BDL	BDL	1.662
B-5	BDL	0.001	BDL	0.031	1.391	0.001	BDL	BDL	0.047
B-6	BDL	BDL	BDL	0.218	0.403	0.005	BDL	0	0.012
T-1	0.014	0.003	BDL	0.023	2.192	0.005	4.722	0.003	0.023
I-1	BDL	BDL	BDL	0.024	0.959	0.001	BDL	0	0.022

BDL: Below Detection Limit

Table 3. USEPA and WHO drinking water quality standards

Parameter	USEPA standards Maximum Contamination Levels (MCLs (ppb))	World Health Organization ((WHO) ppb)
Sb	6	20
As	10	10
Ba	2000	700
Be	4	
Cd	5	3
Cr	100	50
Cu	1000	2000
Pb	15	10
Hg	2	
Se	50	10
Tl	2	
U	30	15
Al	50 to 200	200
Fe	300	300
Mn	50	200
Ag	100	
B		500
Ni		20
Mo		70
Zn	5000	

From Table 2, we found that the concentrations of all trace elements are far below the current WHO and USEPA maximum limits.

The maximum and minimum of Arsenic (As) levels range from 4.680 ppb to BDL. As far as toxicity is concerned, the concentrations of As were found to be below the current WHO and USEPA maximum limits for drinking water (10 µg/L). The As concentrations for bottled spring waters (B-2, B-3) were higher than the other samples, while the concentration of As in the tap water sample (T-1) was in the middle range. The As concentration of iceberg sample (I-1) was very low. It has been noted that selenium can counteract the effects of excess arsenic when the two elements are combined, thus reduce the toxicity in living creatures.

The WHO and USEPA guideline limit for Selenium (Se) is 50 µg/L. The range of Se was between 0.014 and 0.169 ppb, while samples B-3, B-6 and I-1 are below the detection limit. All the results are far below the guideline limit. It has been proven that selenium is an antioxidant that neutralizes free radicals as a part of some enzymes (e.g., glutathione peroxidase) or by working in conjunction with vitamin E. So, it protects people from some kinds of cancer and heart disease.

The Ag level ranges between 0.001 to 0.003 ppb with samples B-2, 3, 4, 6 and I-1 below detection limit. All results are far below the guideline limit (100 ppb).

The Al levelis pretty lower for all samples, except samples T-1, I-1. The tap water T-1 has the highest level of Al which can originate from the pipeline system and storage tanks.

The Cd levels of all samples are below the detection limit and all results are below the WHO and USEPA standard limit (5 - 3 ppb).

The Pb level of sample T-1 is higher than all other samples which are below the detection limit. The higher level of Pb (4.722 ppb) in T-1 probably originates from the pipe system. The lead is present in tap water to some extent as a result of its dissolution from natural sources but primarily from household plumbing system in which the pipe solder, fittings, or service connections to homes contain lead (Saleh, 2001 and Al-Saleh, 1998). The amount of lead dissolved from the plumbing system depends on several factors, including the presence of chloride, dissolved oxygen, pH, temperature, water hardness and the standing time of water (Schock, 1989 and 1990). Lead is a highly toxic metal with no known biological benefit to humans. Its adverse health effects include various cancers, adverse reproductive outcomes, cardiovascular and neurological diseases (Watt, 2000).

The bottled samples B-1, B-2, B-4, B-6 and tap water sample possess higher Cr level than that of iceberg sample I-1, bottled samples B-3 and B-5. The toxicity of Cr is related to the reduction of chromate to Cr^{III} and radicals produced by the reaction. Trivalent chromium deficiency is characterized by disturbances in glucose, lipid and protein metabolism, whereas the hexavalent is place among the toxic metals. The biologic activity of trivalent chromium is mainly focused on the regulation of glucose metabolism as a part of the glucose tolerance factor that enhances insulin activity.

The concentrations of Ni of all samples are much lower than the proposed WHO standard (20 ppb).

The U levels of samples B-1, B-2, B-3, B-4 are higher than the other samples. All results are below the WHO guideline and USEPA limit.

All bottled water samples contain higher levels of Sb than tap water and iceberg water do. With concentrations ranging from 0.031 to 0.521 ppb, all samples were below the proposed WHO and USEPA limits of 6 ppb. It was recently reported that a continual release of Sb from polyethylene terephthalate (PET) containers is observed and that the Sb concentration in bottled waters mainly reflects the duration of their storage (Rish, 2003 and Shotyk, 2006).

Sample B-1 and B-4 have higher Ba levels than any other samples. A great diversity of concentration among all the samples ranged from 0.403 to 121.286 ppb. All samples are below the proposed WHO standards (700 ppb).

The Be levels of all samples are very consistent. All results are below the proposed WHO and USEPA limit (4 ppb).

The Tl levels of all samples are very low, which is low than the proposed USEPA limit (0.5 ppb).

Sample B-1, T-1 and I-1 exhibit higher levels of Cu than those of other samples. The higher level of Cu in sample T-1 can also originate from pipeline system and storage tanks.

The level of Mn ranges from 0.041 to 5.897 ppb, and 4 samples are below the detection limit. All results are far below the proposed USEPA limit (50 ppb).

The levels of Zn in these samples vary significantly from BDL to 59.462 ppb. The natural concentration of Zn in water depends on a multitude of factors such as the nature and age of geological formations through which the water flows, along with biological, physical and chemical conditions (Peganova, 2003). However, much higher concentration of Zn observed in tap water is probably due to the conditions of the pipe system.

No health-related guideline is available for the following elements: Co, V, and Th.

Cobalt (Co) is an essential micronutrient that enters the body in vitamin B12 and subsequently participates in the formation of red blood cells and DNA. No information is available on the maximum allowable level of cobalt in water since it is not a cumulative toxic element. The minimum and maximum levels of Co are BDL and 0.244 ppb, respectively.

The levels of V in all samples are very low. The B-2 sample has been observed to have the highest level (3.284 ppb).

The Th levels in all samples are very low and consistent.

Conclusions

Through this study, we have found that the trace element concentrations in all samples we investigated are far below the current WHO and USEPA maximum limits. This study has demonstrated that ICP-MS is a powerful technique to achieve trace element analysis of water with high accuracy.

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