Geochemical Multi-element ICP-OES Analysis of Borehole Waters from SE Anatolia

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ABSTRACT

Water supply from boreholes is today used by people from rural areas of Turkey more commonly due to the reduction of available surface water. For this reason, the concentrations of Al, As, B, Be, Ca, Cd, Co, Cr, Fe, Hg, K, Mg, Mn, Mo, Na, Ni, Pb, Se, Sn, and Zn in borehole waters of the Diyarbakır province (SE Anatolia) were determined in this study. Thirty borehole waters were sampled from different towns and villages. The samples were analyzed by inductively coupled plasma optical emission spectrometry (ICP–OES). The results of the analyses were compared with guidelines as set by Turkey, the WHO, and the EU. From the results it could be concluded that the ICP-OES method can be considered useful for the routine determination of trace elements in waters and similar matrices. For quality control purposes, the certified reference material TMDW-B Drinking Water was employed for validation. The recovery values were in the range of 93–101%. The Al, As, B, Be, Cd, Co, Cr, Hg, Mn, Mo, Ni, Pb, and Sn concentrations in the samples were found lower than the recommended LOD. The concentrations found were in the range of 12.71–111.4 mg/L for Na, 0.76–3.07 mg/L for K, 9.62–115.5 mg/L for Ca, 2.69–41.85 mg/L for Mg, <LOD of 0.12 mg/L for Se, <LOD of 0.21 mg/L for Fe, and <LOD of 0.52 mg/L for Zn. While some of the results were at acceptable guideline limits, the Se amount in six samples was higher than the suggested limit of >10 µg/L.

INTRODUCTION

Water is an indispensable component for life. The human race in this 21st century is faced with unprecedented challenges imposed by water scarcity, pollution, and water quality deterioration. Rapid industrialization and population growth in the last few decades have caused an increase in the demand for borehole water as well as a significant impairment in water quality throughout the world (1, 2). Groundwater and surface sources are known to contain various elements, some of which have been implicated to impair human health and cause disease (3). A variety of elements is commonly present in virtually all drinkable water which includes Al, As, B, Be, Ca, Cd, Co, Cr, Fe, Hg, K, Mg, Mn, Mo, Na, Ni, Pb, Se, Sn, and Zn. They are generally found in small quantities and play an important role in the body's metabolism (4-7). On the other hand, the World Health Organization (WHO) reported that high dietary intake of selenium (Se) per day of 6–21 µg for infants and children, 26 and 30 µg for adolescent females and males, respectively, and 26 and 35 µg for adult females and males, respectively, has been identified to cause gastrointestinal disturbances, discoloration of the skin, loss of hair, nail changes, and tooth decay. The negative effects of lead (Pb) on health were already known to ancient civilizations. In 2013, WHO estimated that lead poisoning resulted in 143,000 deaths, and causes 600,000 new cases of children born with intellectual disabilities each year (8,9).

The main sources of Pb contamination for humans are food and water. Children are more susceptible to the effects of Pb because they absorb Pb more readily than adults. Pb from environmental pollution is not carcinogenic, but even a low Pb exposure has detrimental and long-lasting effects on the renal, hemopoietic, and nervous systems (10, 11).

Copper (Cu) is a naturally occurring element found in rocks, soil, water, plants, and animals. It is an essential element required for the growth of both plants, animals, and humans (12). But an excess of Cu can produce toxicological effects, including vasodilation, flushing, and cardiomyopathy (13).

Zinc (Zn), one of the most essential multi-elements, is a co-factor for more than 200 enzymes, and a deficiency causes nutritional problems. However, an excess of this metal can cause disturbances in the energy metabolism or an increase in oxidative stress, growth retardation, altered immune response, disturbed pregnancy, weight loss, and anorexia, among others (14).

Some groundwater, surface water, and well water contains the arsenic (As) species of arsenate (As^{5+}) and arsenite (As^{3+}), which have become one of the most serious problems (15,16).

Some essential trace elements in water are V, Cr, Mn, Fe, Co, Cu, Zn,

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Se, Sr, K, Ca, Mg, and Mo (17,18). Recent environmental studies have been devoted to analyzing trace elements in order to establish the concentration of organic and inorganic pollutants and their chemical composition to protect the health of the population (19-23). Table I provides a comparison of the daily maximum allowable concentrations (MAC) of elements as regulated by WHO, the European Union (EU), the United States, Canada, Turkey, and the P.R. of China. Table II lists the daily intake of elements per day through food, water, and air, toxic quantities, mean levels in the body, and half-life of the elements (24-27).

Water scarcity in some countries, such as Turkey, has become a critical issue in recent years, while the concern that fresh water will become a scarcer source in the future has been reported (28, 39). The use of borehole water is increasing in many communities of the world due to the reduction of surface water arising from the unobvious use and pollution from anthropogenic activities, etc. In this study, the analysis of borehole waters from 30 different towns and some rural areas of the Diyarbakır province (South East Anatolia of Turkey) have been investigated. The main aim of this study was to check whether the trace element levels comply with international standards for borehole waters from 30 different points of Diyarbakir.

TABLE I
Maximum Allowable Concentration for Trace Elements in Drinking Water as Regulated by the Various Countries (24-27)

Element	WHO	E.U.	U.S.	China	Canada	Turkey
As	10 µg/L	10 µg/L	10 µg/L	50 µg/L	10 µg/L	10 µg/L
Sb	NS	5.0 µg/L	6.0 µg/L	NS	6.0 µg/L	NS
Ba	700 µg/L	NS	2.0 mg/L	NS	1.0 mg/L	NS
B	2.4 mg/L	1.0 mg/L	NS	NS	5.0 mg/L	1.0 µg/L
Cd	3.0 µg/L	5.0 µg/L	5.0 µg/L	5 µg/L	5.0 µg/L	5.0 µg/L
Cr^{6+}	50 µg/L	50 µg/L	0.1 mg/L	50 µg/L	0.05 mg/L	50 µg/L
Cu	2.0 mg/L	2.0 mg/L	NS	1.0 mg/L	1.0 mg/L	2.0 mg/L
Pb	10 µg/L	10 µg/L	15 µg/L	10 µg/L	10 µg/L	10 µg/L
Hg	6.0 µg/L	1.0 µg/L	2.0 µg/L	0.05 µg/L	1.0 µg/L	1.0 µg/L
Ni	20 µg/L	20 µg/L	20 µg/L	NS	NS	20 µg/L
Se	40 µg/L	10 µg/L	50 µg/L	10 µg/L	10 µg/L	10 µg/L
Ca	NS	NS	NS	NS	200 mg/L	NS
Mg	NS	NS	NS	NS	50 mg/L	NS
Zn	NS	NS	NS	NS	5.0 mg/L	5.0 mg/L
Fe	NS	200 µg/L	NS	NS	0.30 mg/L	200 µg/L
Mn	NS	200 µg/L	NS	NS	0.05 mg/L	50 µg/L
Ag	NS	NS	NS	NS	0.05 mg/L	NS
U	30 µg/L	NS	NS	NS	0.10 mg/L	NS
Na	200 mg/L	200 mg/L	NS	NS	200 mg/L	200 µg/L
Al	NS	200 mg/L	NS	NS	NS	NS

NS : Not specified, indicates that no standard exists.

EXPERIMENTAL

Instrumentation

A PerkinElmer® Optima™ 2100 DV inductively coupled plasma optical emission spectrometer (ICP-OES) (PerkinElmer, Shelton, CT, USA) was used for the determination of Al, As, B, Be, Ca, Cd, Co, Cr, Fe, Hg, K, Mg, Mn, Mo, Na, Ni, Pb, Se, Sn, and Zn in water samples by considering the related references (30, 31). Table III lists the instrumental operating conditions and the most sensitive analytical lines of the analytes without spectral interference in the sample matrix. The concentrations of As, Se, and Hg were measured by using a continuous-flow hydride generation apparatus (Chemifold+Gas/Liquid Separator Manifold, PerkinElmer, Shelton, CT, USA). The experimental parameters are listed in Table III.

Sampling

The borehole waters sampled were in the Diyarbakır province (37° 55' N, 40° 14' E), located at the North Mesopotamia and Southeastern Anatolia regions of Turkey. The total area of Diyarbakir encompasses 15,355 km^2, of which about 2000 km^2 are classified as urban. The continental climate is subtropical (28, 29). The area is a basin surrounded by mountains, one of which is Karacadag (black mountain), an extinct volcanic mountain. The population of the Diyarbakır area (urban and rural) in 1997 was 1,282,678 and in 2014 reached 1,607,437. In this area, 30 sampling stations were established with the main purpose of identifying critical situations of water quality degradation as a result of urban pollution (32).

Water samples were collected according to the standard method (30). Details about the sampling points for the 30 borehole samples are listed in Table IV. The samples were taken from the tank containing the borehole water used both for drinking and irrigation purposes by the local inhabitants. In order to prevent any possible contamination from metal cations, the water sam-

TABLE II
Elements Taken Daily Through Nutrient, Air, Food, and Water (25)

Elements	Food & Water (mg/daily)	Air (mg/daily)	Toxic Effects (mg/daily)	Levels in Body (mg/daily)	Half-life (mg)
Sb	1.000	0.0017	100	7.9	38
Cu	1.325	0.0014	250-500	72.0	80
Ba	0.735	0.030	200	22	65
Be	0.012	0.00004	-	0.03	180
Bi	0.020	0.00076	-	0.23	5
Hg	0.025	-	-	-	70
Zn	14.500	0.0168	-	2300	933
Fe	15.000	0.084	-	4200	800
Ag	0.600	-	60	1	5
As	0,002	-	2	-	-
Cd	0.160	0.0074	3	50	200
Sn	7.300	0.0006	2000	17	35
Co	0.390	0.00012	500	1.5	9.5
Pb	0.300	0.046	-	12.0	1460
Cr	0.245	0.0011	200	1.8	616
Mn	4.400	0.0288	-	12	17
Mo	0.335	0.006	-	9.3	5
Ni	0.600	0.00236	-	10	667
Ti	1.375	0.0014	-	9	320
U	0.050	-	-	0.7	100
V	0.116	0.00916	-	22	42
Zr	0.490	-	-	420	450

ples were stored in sterile polyethylene containers (1.0 L) previously washed with HNO_3, followed by rinsing with ultrapure water. At the collection points, the samples were acidified by adding concentrated HNO_3 (1.5 mL/L) to reach a pH of 2.0, and were then brought to the laboratory (33). These samples were placed into the refrigerator until analysis. The time from sampling to measurement varied from 2 to 5 days. All of the samples were analyzed at the same time and under the same instrumental conditions.

TABLE III
ICP-OES Instrumental Operating Conditions

Parameters	ICP-OES	HG-ICP-OES
RF Power	1450 W	1375 W
Plasma Gas Flow Rate	15 L/min	17 L/min
Auxiliary Gas Flow Rate	0.2 L/min	0.2 L/min
Nebulizer Gas Flow Rate	0.6 L/min	0.8 L/min
Sample Flow Rate	1.5 L/min	1.0 L/min
Viewing Mode	Axial - Radial	Axial
Source Equilibration Time	15 s	20 s
Read delay	45 s	60
Nebulizer	Cross-Flow GemTip™ Nebulizer (HF resistant)	Continuous Flow Hydride Generation
Read	Peak Area	Peak Area
Replicates	3	3
Background Correction	2-point (manual point correction)	2-point (manual point correction
Spray Chamber	Scott-type Spray Chamber	Scott-type Spray Chamber
Detector	CCD	CCD
Purge Gas	Nitrogen	Nitrogen
Shear Gas	Air	Air
Gas	Argon	Argon
Analytical Wavelengths	Al 396.153 nm Sn 189.927 nm B 249.771 nm Be 313.107 nm Ca 393.366 nm, Cd 228.804 nm Co 228.616 nm Cr 267.716 nm Fe 238.204 nm K 766.490 nm Mg 280.271 nm Mn 257.610 nm Mo 202.031 nm Na 589.592 nm Ni 231.604 nm Pb 220.353 nm Zn 206.200 nm	Hg 194.168 nm Se 190.026 nm As 188.979 nm

TABLE IV
Details of Sampling Points

Villages/ Towns	Population	Borehole Depth (m)	Tank Volume (L)	Villages/ Towns	Population	Borehole Depth (m)	Tank Volume (L)
Develi	586	180	100	Haciosman	227	290	50
Kabahidir	532	152	50	Kozan	761	106	75
Egertutmaz	347	140	50	Kurtkayasi	93	400	50
Tasdirek	595	140	50	Nahırkiraci	429	152	50
Körtepe	880	148	50	Sati	941	180	50
Pınaroglu	154	152	50	Bagivar	8832	352	700
Sarıdalli	441	384	100	Çarikli	4457	400	50
Yukarımollaali	194	180	75	Alpu	304	455	50
Beneklitas	199	78	50	Bahçelievler	293	40	100
Gözegöl	166	400	50	Basil	517	412	50
Alçak	124	100	50	Gevendere	1042	54	75
Yolboyu	2773	114	150	Güvercinlik	372	28	100
Büyükkadi	544	258	75	Sancar	142	150	50
Doguçanakçi	79	300	50	Tanısik	21	168	50
Erimli	953	300	50	Yukarınasirlar	128	80	50

RESULTS AND DISSCUSSION

Standard Solutions, Reagents, and Calibration Curves

The working standards were prepared by serial volume/volume dilution in polypropylene vials (Sarsted®, Germany). Micropipettes (Eppendorf®, Germany) with disposable tips were used for pipetting all solutions. The reagents and acids were of analytical grade and used without further purification.

All standard solutions were prepared by using ultrapure water. The standard solutions for the analysis were made up of concentrations for Ca, Na and Mg at 50, 100, 150, and 200 mg/L; and for K, Cr, Mo, Sn, Cd, Co, Be, Ni, Pb, Al, B, Fe, Mn, and Zn at 0.05 mg/L, 0.1 mg/L, 0.25 mg/L, 0.5 mg/L, and 1.0 mg/L. They were prepared with dilute distilled water from high-purity ICP multi-element stock solutions of 1000 mg/L (No. 1213901, High Purity Standards, Charleston, SC, USA).

The As, Se, and Hg concentrations were determined by using the hydride generation system of the ICP-OES. The Hg, As, and Se standard solutions (5.0, 10, 20, and 40 µg/L) were prepared in 5% HCl 0.2% (w/v), $NaBH_4$ was used in the experiments. A 1.0-mL mixture of ascorbic acid and KI (prepared by dissolving 5.0 g ascorbic acid and 5.0 g of KI in 100 mL ultrapure water) was added to the samples containing 5% HCl for hydride generation of As. Then, 2 to 3 drops of $KMnO_4$ (5% w/v) were added to each of the samples for hydride generation of Hg. The standards and samples diluted with HCl (1:1, v/v) were placed into hot water (90 ºC) for 20 minutes. After cooling to room temperature, they were subjected to the hydride generation procedure for Se. Ultrapure water, acidified with Suprapur® nitric acid (E-Merck, Germany) was used as the calibration blank and for all dilutions. The standard calibration curves were found to be linear with a correlation coefficient of 0.999. The concentration of each element was calculated using calibration curves. Some of the trace elements in the samples, which were outside the standard calibration, were analyzed by dilution with ultrapure water.

The limit of detection (LOD) and the limit of quantification (LOQ) for each metal were determined as follows: the analytical curves were performed for 10 independent analyses of a blank solution spiked with the metal at a level of lower concentration. The LOD and LOQ were calculated from the standard deviation (α) of the determinations (LOD = 3 α and LOQ = 10 α), and the analytical results are listed in Table V (17,18).

High purity certified reference material (CRM) of TMDW-B Drinking Water (High Purity Standards, Charleston, SC, USA) was used to determine the precision and accuracy of the method. The CRM sample was diluted with ultrapure water and acidified with nitric acid according to the range of the standard solution. The CRM sample was analyzed in triplicate by ICP-OES, and the results listed in Table V were in good agreement with the certified values.

The increase in population in the Diyarbakır province means that the available terrestrial water is not sufficient and resulted in also using borehole water. These waters are used for both drinking and irrigation purposes. Thus, the importance of constant analysis of these waters is paramount. Table IV lists the borehole water depths and the number of people of each area benefiting from these waters. The trace elements Al, As, B, Be, Ca, Cd, Co, Cr, Fe, Hg, K, Mg, Mn, Mo, Na, Ni, Pb, Se, Sn, and Zn were detrmined by using ICP-OES analysis. For this study, the LOD and LOQ values were determined for each element, and the values were found to be within tolerable limits (Table V). A certified reference

TABLE V
Analytical Characteristics of the ICP-OES for the Determination of Al, As, B, Be, Ca, Cd, Co, Cr, Fe, Hg, K, Mg, Mn, Mo, Na, Ni, Pb, Se, Sn, and Zn in CRM TMDW-B Drinking Water Sample

Elements	LOD (µg/L)	LOQ (µg/L)	Certified (µg/L)	Found (µg/L)	Recovery (%)
Al	5.7	18.9	125	121.3±10.2	97
As[a]	0.022	0.073	10	10.1±0.8	101
B	11.2	37.3	150	145±7.5	97
Be	1.2	4.0	15	14.8±0.9	99
Ca	1.2	4.1	31000	30180±380	97
Cd	0.035	0.116	10	9.8±0.5	98
Co	2.1	7.0	25	24.1±0.9	96
Cr	0.05	0.17	20	19±0.8	95
Fe	0.75	2.45	90	89±1.5	99
Hg1	1.0	3.33	-	-	-
K	1.9	6.33	2500	2456±41	98
Mg	0.9	3.0	8000	7913±75	99
Mn	3.2	10.7	40	38.2±1.1	96
Mo	4.1	13.7	110	102±5.6	93
Na	5.4	8.0	22000	21012±312	96
Ni	3.4	11.3	60	56.2±1.3	94
Pb	0.095	0.32	20	19.2±0.6	96
Se1	2.1	7.00	11	10.8±0.7	98
Sn	-	-	-	-	-
Zn	0.048	0.16	75	76±1.5	101

[a] Measured by HG-ICP-OES.

material was used to verify the accuracy of the method, and the results were in good agreement (Table V). The standard calibration curves were found to be linear with a correlation coefficient of 0.999; the concentration of each element was calculated using calibration curves. The concentrations of Na, K, Ca, Se, Fe, Mg and Zn in the 30 samples were determined by ICP-OES at the respective wavelengths, and the results are shown in the Table VI. The concentrations of Al, As, B, Be, Cd, Co, Cr, Hg, Mn, Mo, Ni, Pb, and Sn in the samples were found lower than the LOD.

This study showed that the elements Al, As, B, Be, Ca, Cd, Co, Cr, Fe, Hg, K, Mg, Mn, Mo, Na, Ni, Pb, Sn, and Zn as determined in the 30 borehole water samples were within the allowable limits. However, the Se concentration in all six samples was high (0.11–0.12 µg/L), while the MAC limit is >0.01 mg/L. The results of the analysis, as shown in the Table VII, were compared with the regulated limits from Turkey (TS-266), WHO, and the EU. Several studies have revealed that Se is important to health, but a very low Se status (<10 µg) in humans has been associated with juvenile, multifocalmyocarditis (Keshan disease), and chondrodystrophy (Kaschin-Beck disease). A high dietary intake of Se (>1000 µg), as shown in high urinary Se levels, manifests itself in gastrointestinal disturbances, discoloration of the skin, and tooth decay (34,35). Table VII lists the WHO recommended dietary allowance of Se for male and female according to age as determined.

In a study of well waters in the Urfa province (SE Anatolia), the Se levels were found to be higher than the recommended legal regulations (>0,01 mg/L) (36). The Urfa province is neighboring Diyarbakır and is close to the Euphrates. In this study, Se was found to be high in borehole water samples. In areas close to the river, trace metal concentrations are high, but they decrease closer to the mountainous regions. For instance, the region around the Karacadag Mountain is covered with porous, hard, black volcanic rocks, which may prevent the leakage of elements to the borehole waters. The high amount of Se in areas close to the Tigris River might likely be contaminated from soil, sandy soil, or agricultural waste.

The analytical results show that the borehole waters in Diyarbakır contain major and toxic trace elements (Al, As, B, Be, Ca, Cd, Co, Cr, Fe, Hg, K, Mg, Mn, Mo, Na, Ni, Pb, Se, Sn, and Zn), but they are present at very low levels, which makes the borehole waters tested an unpolluted and safe source. Thus, all of these trace elements, except Se, were within tolerable limits. Table VII lists the recommended daily allowance for Se, which shows that the borehole water samples in the areas of Sat, Doguçanakçi, Kozan, Haciosman, Çarıkli, and Güvercinlik have higher than allowed values and thus can be a health hazard. However, in all samples, the concentrations of Al, B, Co, Mn, Pb, Sn, As, Be, Cd, Cr, Hg, Mo, and Ni were found to be lower than the LOD.

CONCLUSION

The results of this study demonstrate that the ICP-OES method can be considered useful for the routine determination of trace elements in waters and similar matrices, as well as for quality control purposes. The accuracy of the method was verified and compared well with the

TABLE VI
Na, K, Ca, Se, Fe, Mg, and Zn Determination in Borehole Waters by ICP-OES[a] (Se concentrations were measured by HG-ICP-OES)

Sample Points	Na (mg/L)	K (mg/L)	Ca (mg/L)	Se (mg/L)	Fe (mg/L)	Mg (mg/L)	Zn (mg/L)
Sati	35.30	1.65	54.48	0.11	ND	20.18	ND
Doguçanakçi	12.71	0.90	60.22	0.12	ND[b]	15.32	0.16
Kozan	39.38	1.77	46.71	0.12	ND	23.73	ND
Haciosman	46.30	0.97	40.22	0.11	ND	20.08	ND
Bagivar	46.28	2.30	50.44	0.10	ND	25.28	0.12
Yk.Mollaali	18.01	1.40	31.98	0.07	ND	17.32	ND
Çarıkli	30.79	2.02	59.46	0.11	0.09	28.62	0.52
Kurtkayasi	20.33	1.99	40.79	0.09	ND	23.92	ND
Kabahidir	20.97	0.76	41.60	0.08	ND	15.76	ND
Egertutmaz	39.95	1.07	50.68	0.08	ND	18.66	ND
Tanısik	24.66	2.61	103.2	0.10	0.10	38.70	ND
Bahçelievler	22.38	1.11	42.79	0.09	ND	21.32	0.08
Sancar	19.64	1.05	57.71	0.08	ND	22.80	ND
Basil	21.28	2.35	115.5	0.09	ND	41.85	ND
Gevendere	21.65	2.51	60.90	0.08	ND	33.12	ND
Güvercinlik	17.74	2.16	95.88	0.12	ND	33.82	0.06
Yk.Nasirlar	19.34	1.35	53.93	0.07	ND	23.14	ND
Alpu	34.84	0.94	37.26	0.07	ND	13.11	ND
Körtepe	18.25	4.62	71.06	0.08	ND	23.80	ND
Tasdirek	16.14	0.79	55.48	0.08	ND	19.09	ND
Yolboyu	18.84	3.07	14.37	ND	ND	12.79	ND
Beneklitas	35.01	2.99	57.33	ND	ND	38.55	ND
Sarıdalli	87.24	3.02	34.62	0.07	ND	16.87	0.15
Büyükkadi	73.21	1.23	28.54	ND	ND	6.996	0.17
Develi	66.02	1.72	9.623	ND	0.21	5.207	ND
Alçak	19.13	1.61	36.62	0.08	ND	26.43	ND
Erimli	72.09	1.31	52.65	0.07	0.10	10.52	0.42
Gözegöl	22.84	2.69	59.23	0.09	ND	27.88	ND
Pınaroglu	53.45	1.54	19.93	0.07	0.20	12.11	ND
Nahirkıraci	111.4	0.92	11.17	ND	ND	2.69	ND

[a] The Al, As, B, Be, Cd, Co, Cr, Hg, Mn, Mo, Ni, Pb and Sn concentrations were lower than the LOD and were not listed in this table.
[b] ND: Not detected.

certified values. Analysis of the borehole waters revealed that six of the samples had higher Se levels than allowed by legal regulations. The concentrations of Na, K, Ca, Se, Fe, Mg, and Zn in the 30 samples were found to be lower than the maximum allowed values. The elements Al, As, B, Be, Cd, Co, Cr, Hg, Mn, Mo, Ni, Pb and Sn were found to be lower than the LOD. However, the Se concentrations in six samples were higher than the MAC limit of >0.01 mg/L. Recovery values were achieved in the 93–101% range for the CRM TMDW-B Drinking Water Sample. The concentration ranges of Na, K, Ca, Mg, Se, Fe, Zn were 12.71–111.4 mg/L, 0.76–3.07 mg/L, 9.62–115.5 mg/L, 2.69–41.85 mg/L, <LOD 0.12 mg/L, <LOD 0.21 mg/L, and <LOD 0.52 mg/L, respectively. The results obtained in this study were in good agreement with the legal limits for other elements such as Sb, Cu, Ba, Bi, Ag, Sn, Ti, U, V, and Zr.

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TABLE VII
Recommended Dietary Allowances for Se (34, 35)

Age	Male (µg)	Female (µg)	Pregnancy (µg)	Lactation (µg)
Birth to 6 months	15	15	-	-
7–12 months	20	20	-	-
1–3 years	20	20	-	-
4–8 years	30	30	-	-
9–13 years	40	40	-	-
14–18 years	55	55	60	70
19–50 years	55	55	60	70
51+ years	55	55	-	-

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