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Effect of High Aluminum Concentration in Water Resources on Human Health, Case Study: Biga Peninsula, Northwest Part of Turkey

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Abstract Widespread and intense zones of silicified, propylitic, and argillic alteration exist as outcrop around the Biga Peninsula, NW Turkey. Most of the springs in the study area surface out from these altered volcanic rocks. The concentrations of aluminum (Al) in these springs ranged from 13.17 to 15.70 ppm in this region. These high levels of Al were found to exceed the maximum allowable limits (0.2 ppm) depicted in national and international standards of drinking water quality. Therefore, the effect of high Al in water resources on human health was evaluated in this research. A total of 273 people aged above 18 years and living in the Kirazli region (whose water supply is from springs emerging from these alteration zones) and in the Ciplak–Halileli region (whose water supply is provided from an alluvium aquifer) were selected as the research group. For this group, a questionnaire was completed that contained questions on descriptive characteristics of humans and a Mini-Mental State Examination (MMSE) was administered by the authors using the face-to-face interview technique. A neurological examination was then performed by the neurology specialist as a second-stage investigation. Finally, 10 ml of venous blood samples were obtained from these people as a third-stage analysis to determine the serum Al levels together with vitamin B_{12}, folic acid, and thyroid-stimulating hormone parameters. The result typically revealed that the MMSE score was less in 31.9% and there was no statistically significant difference between the two regions. However, the result also showed that neuropathy in the history (including a careful past medical history) was significantly higher in the Kirazli region.

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Aluminum (Al) is found in large amounts in the Earth's crust in the form of various compounds (oxygen, fluorine, silica, etc.). It is very rarely found in its free form in nature. It is found in low amounts in living organisms as an element. In its natural form, bauxite mineral is the main source of Al and is used in various fields in industry (Nordberg 1993). Al is generally detected in low concentrations in waters that are used for drinking water supply purposes. According to the US Environmental Protection Agency (US EPA), World Health Organization (WHO), and the Turkish Ministry of Health, the maximum Al concentration in the drinking water should not exceed 0.2 ppm (TC: The Official Gazette 2005; WHO 2008).

The earliest study describing Al as a potential neurotoxic substance was an experimental study that dates back to the early 1900s. In 1965, experiments carried out in rabbits indicated that there could be a relationship between Al and Alzheimer's disease (AD). In 1973, increased cerebral Al levels were reported in AD patients (Flaten 2001). Dialysis encephalopathy observed in patients with chronic renal failure in the same period supported these findings (Flaten 2001). In the following years, studies indicated that the brain had a predisposition for Al-induced damage and that consumption of food containing Al additives or water containing high levels of Al could play a role in AD development (Solfrizzi et al. 2003).

Epidemiological studies carried out in various parts of the world demonstrated a relationship between the drinking water's Al levels and AD, dementia, and cognitive damage (Flaten 2001; Molloy et al. 2007; Meyer-Baron et al. 2007). Postmortem studies have found increased cerebral Al levels in disorders, such as; AD, amyotrophic lateral sclerosis and Parkinson's disease (Oteiza et al. 2004).

On the other hand, there are also reports that found no relationship between Al and AD (Flaten 2001). However, different methodologies used in these studies, the multifactorial etiology of AD, cognitive function disorders, dementia, and the difficulties in the diagnosis should be taken into account. In 1996, McLachlan et al. (1996) reported 2.5 times higher AD risk in patients who were exposed to drinking water containing high levels of Al in their case–control study on brain autopsies. Results of the scientific studies so far has suggested that being exposed to high levels of Al for a long time might pose a risk of neurological damage.

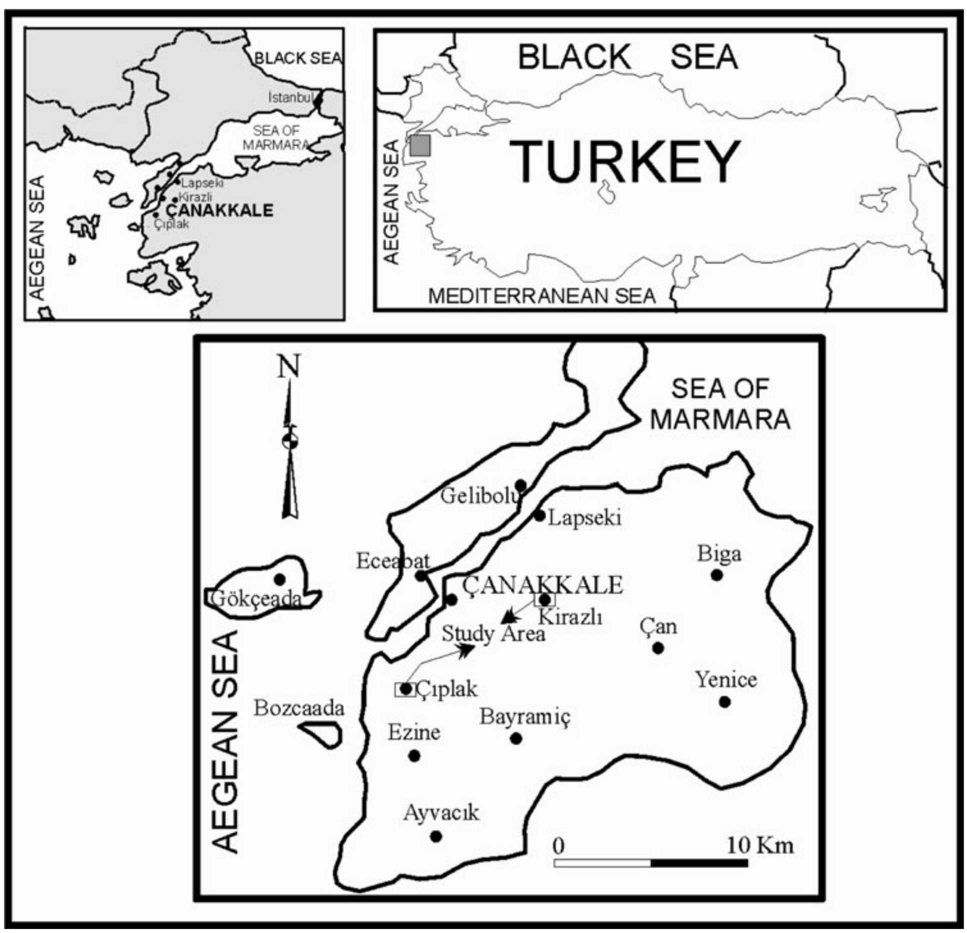
Based on these fundamentals, this study was carried out in the Kirazli region of the Biga Peninsula located in the northwest Turkey, in order to evaluate the potential of Al to influence cognitive functions in the people living in areas where acidic waters with high Al concentrations are consumed.

Characteristics of the Study Area

The study was carried out in the Biga Peninsula situated in the northwestern parts of Turkey. Two regions (Kirazlı and Ciplak–Halileli) were selected for this study. The Kirazlı region, located 35 km from the province of Canakkale, was the main point of concern. The control group, on the other hand, was selected from the inhabitants of the Ciplak–Halileli region, which is located 30 km away from the province center and about 5 km away from the world-renown ancient city of Troia (Fig. 1).

Biga Peninsula is an active tectonic region. The oldest rock in the study area is Paleozoic-age metamorphic rocks,

Fig. 1 Location of study area



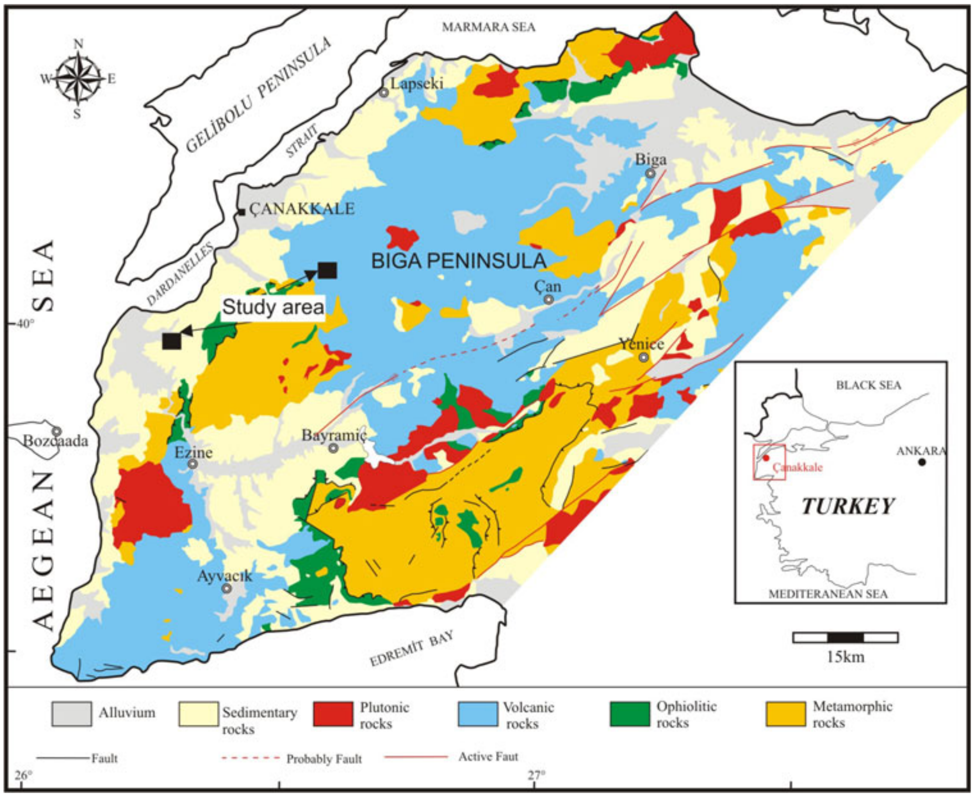


Fig. 2 Regional geology in Biga Peninsula (modified from MTA (2002)

such as schist and marble, which are commonly known as the Kazdag group. Rocks of the so-called Karakaya complex, such as sandstone, shale, ophiolite, and metavolcanics, were settled on this group with a tectonic boundary (Fig. 2). Volcanic and sedimentary rock series cover these units in different parts of the peninsula. Volcanic rocks are the dominant rock types in the region. Most of these rocks are altered and fractured, due to the effects of active faults. Neogene-age sedimentary rocks overlie these rocks. These sediments consist mostly of fine-grained components, such as sand, silt, and clay and might include thick coal veins in different layers. All of the rocks are covered by Quaternary-age alluvium (Baba and Gunduz 2009).

Volcanic rocks of the region generally consist of andesite, basalt, tuff, and agglomerate. Although the volcanic rocks have some water-bearing potential, they do not form good aquifers of regional extent. Nevertheless, their cooling fractures extend several meters in depth, providing a good avenue for deep penetration and circulation of groundwater. Several springs emerge from volcanic rocks in the Biga Peninsula. Altered volcanic outcrops are abundant around the Kirazlı region. The study area is underlain by a sequence of andesitic to dacitic lithic and crystal-lithic tuffs whose primary textures are largely obscured by a blanket of intense silica and clay alteration. Several springs originate from this unit in the study area, as well as in its vicinity. The low pH values measured in most springs suggest that the groundwater originating from the volcanic areas are affected by mineralization. The Kirazlı region was included in the study, as it has water supplies characterized by high acidic content and Al levels.

Alluvium in the plain has great importance as a medium to hold freshwater and facilitate formation of the water table. The depth of the water table from the surface of the area changes according to seasonal rainfall, but it is not deeper than about 3 m below the surface, even at the end of the driest summer period. This water can be easily reached and used in many parts of the plain by dug wells. The drinking water requirements of the Ciplak–Halileli region are extracted from this alluvium aquifer. Alluvium, which is most probably derived from sheet wash deposits, fan deposits, coastal and wind-blown sediments, is observed along the flat terrain. It is mostly fine-grained (clay, silt, sand, and conglomerate) and constitutes the major agricultural fields of the study area. Generally, various confined aquifers are observed below the alluvium aquifers. The aquifer has been exploited extensively as a domestic and irrigation water supply source.

Materials and Methods

The research was designed to be conducted in two phases: The first phase of the study was focused on determining the quality of water resources in these two regions. Therefore, water samples were collected and assessed for the drinking water quality. The second phase included the evaluation of cognitive damage, which could be caused by drinking Al-containing water by the local people living in this region. For this purpose, a total of 273 people who were 18 years of age or older were monitored.

The water samples were analyzed for the presence of any heavy metals and trace elements, including but not limited to Al. One hundred-milliliter water samples were collected from the research area. All samples were then filtered through a 0.45-μm filter and stored in polyethylene bottles at 4°C. The samples were later acidified to pH = 2 conditions by adding 0.5 N HNO_3 to prevent complex formation of trace elements with oxygen. Samples were then analyzed by inductively coupled plasma–mass spectroscopy (ICP-MS) at the Canadian ACME Laboratories.

The target population for this research consisted of people living in the Kirazli and Ciplak–Halileli regions, who were 18 years of age or older. There was no sampling group for the study and the aim was to reach everyone aged 18 or older. The population of the Kirazlı region at the time of this study was 201 people (112 males, 89 females) living in 50 households and they were exposed to high levels of Al in their drinking water. On the other hand, the population of the Ciplak–Halileli region was 921 people (460 males, 461 females) living in 200 households (TSI 2007). Of these totals, 73 people (41 males, 32 females) from the Kirazli region and 164 people (89 males, 75 females) from the Ciplak–Halileli region participated this study on a voluntary basis (Table 1). After informing the local people, three surveys were conducted. First, the groups were asked a number of general descriptive questions using a survey form and face-to-face interview technique. Second, a neurology specialist administered a Mini-Mental State Examination (MMSE) and performed a neurological examination in order to determine the group's cognitive performance. Finally, 10 cm^3 of venous blood samples from the median cubital vein in the antecubital fossa were collected from each person questioned in order to determine the levels of serum Al, vitamin B_{12} (which could be a potential dementia cause), folic acid, and thyroid-stimulating hormone (third-generation TSH). The blood taken from the subjects was centrifuged for 5 min at 3000 rpm in a desktop centrifuge device and the sera were isolated (Young and Bermes 1999). Within the same day, the sera were transported to a laboratory in Istanbul in special boxes containing ice packs to maintain them at a constant temperature of +4°C.

The MMSE is a general-purpose cognitive screening test, measuring orientation, language, concentration, configuration praxis, and memory. It consists of 11 sections compiled under five headings: orientation, recording memory, attention and calculation, anamnesis, language; it is assessed based on a scale of 30 points. The cutoff value for the MMSE was taken as 22. Güngen et al. (2002) performed a study in 2002 in order to evaluate the validity and reliability of slight dementia diagnosis seen in the Turkish population.

Laboratory Procedures

In the sera obtained from the participants of the study, TSH, folic acid, and vitamin B_{12} were studied using the chemiluminescence enzyme immunoassay method, using the Immulite 2000 Siemens (USA) device, and Al was

Table 1 Concentration of heavy metals in water resources in the study area

Metal	Unit	Ciplak–Halileli			Kirazli				
		Groundwater (CH)			Kirazlı Spring (K)				
		2008	2007	SD	2005	2006	2006	2007	SD
Al	ppm	0.012	0.005	0.01	13.21	15.70	13.18	13.17	1.26
Ba	ppb	112.8	92.82	14.13	22	17.83	16.28	18.71	2.42
Co	ppb	0.04	<.02	0.11	20.36	21.62	16.62	19.29	2.13
Cu	ppb	2.4	10.2	5.51	6.9	22.7	3.7	2.2	9.42
Fe	ppb	<10	12	1.41	551	1123	561	1174	342.73
Li	ppb	1.5	5.8	3.04	10.6	11	9.4	9.2	0.89
Mn	ppb	0.7	0.25	0.32	409.22	407.41	364.53	424.73	25.83
Ni	ppb	<0.2	4	2.69	7.2	7.9	7.2	7.6	0.34
Pb	ppb	0.9	0.7	0.14	28.8	51.2	22.6	19.2	14.39
S	ppm	18	0.013	12.72	50	62	42	47	8.5
Si	ppb	9,515	15,016	3,890	15,518	15,516	11,774	14,064	1,767
Zn	ppb	3	17	9.9	77.5	82	85.1	85.1	3.59

studied with the atomic absorption spectrophotometry method using a Shimadzu AA-6300 (Japan) device.

Statistical Analysis

All of the data were evaluated using the SPSS 15.0 software program. Chi-square and Pearson correlation analysis techniques were used in the statistical evaluation and $p < 0.05$ was considered as a statistically significant value.

Ethical Considerations

Participation into the study was performed on a voluntary basis. Permission for the study was taken from the Canakkale Onsekiz Mart University (COMU)-Local Ethics Committee and written approvals of the participants were taken after informing them about the scope of the study.

Results

The concentrations of some heavy metals such as Al, Pb, and Zn are presented in Table 1. Results show that the Al concentrations varied between 13.17 and 15.70 ppm in the water resources in the Kirazlı region characterized by fairly acidic content (pH < 4). This value was detected at a relatively higher level than the Al amount found in the groundwaters of the Ciplak–Halileli region (0.005–0.012) (Table 1). Concentrations of Al in the water supplies coming from altered volcanic rocks, exceeded the US EPA, WHO, and Turkish drinking water standards, which have a maximum allowable level of 0.2 ppm. However, Al concentrations in the alluvium aquifers, which were used by the local people of the Ciplak–Halileli region, were lower than the recommended limits. The main reason for obtaining high element concentrations in the Kirazlı waters is related to the existence of altered geologic formations, which is consist at more than 80% SiO_2, Al_2O_3, and Fe_2O_3 and lower pH values, compared to the Ciplak–Halileli region waters.

A total of 237 people from both regions were interviewed in this study in order to evaluate the effects of drinking from water supplies containing high Al levels. The mean age of the subjects was found to be 51.6 ± 16.3; 54.9% were male and 76.8% were married; 88.6% of the subjects had an education level of primary school or lower; 13.1% of those with an education level of primary school and lower were found to be illiterate (17.7% females, and 7.5% males). No difference was detected between the primary descriptive characteristics of the people in both regions ($p > 0.05$) (Table 2).

Table 2 Demographic properties of the study area

	Kirazli		Ciplak–Halileli		Total	
	n	%[a]	*n*	%[a]	*n*	%[a]
Gender						
Male	41	56.8	89	54.3	130	54.9
Female	32	43.2	75	45.7	107	45.1
p^b	0.787					
Age						
19–44	25	34.2	58	35.4	83	35.0
45–64	33	45.3	66	40.2	99	41.8
65+	15	20.5	40	24.4	55	23.2
p^b	0.727					
Marital Status						
Married	58	79.5	124	75.6	182	76.8
Single	5	6.8	16	9.8	21	8.9
Widow/divorced	10	13.7	24	14.6	34	14.3
p^b	0.713					
Educational status						
Primary school and under	63	85.1	147	89.6	210	88.6
High school and above	10	14.9	17	10.4	27	11.4
p^b	0.456					
Total	73	30.8[c]	164	69.2[c]	237	100.0

[a] Column percentage
[b] Chi-square test
[c] Row percentage

All of the subjects obtained their drinking water from the groundwater networks in their regions. When asked "Do you notice any abnormality, due to the water you use in the region?" 66.2% replied positively. Problems connected to the drinking water were detected in 52.1% of the participants living in the Kirazli region and in 72.4% of those living in the Ciplak–Halileli region, for whom values were found to be statistically significant ($p < 0.05$). Whereas 71.1% of those living in the Kirazli region reported change in color (yellow) due to corrosion and 21.1% reported puncture in their saucepans, due to the water used, 90% of the people living in the Ciplak–Halileli region observed calcification.

Despite the differences in Al levels in their water supplies, no statistically significant difference was detected between the Al, vitamin B_{12}, and TSH levels of the participants living in the two regions ($p > 0.05$). However, a significant difference was detected between their serum folic acid values ($p < 0.05$). Whereas folic acid levels were detected to be 2.9 and lower in 15.1% of those living in the Kirazli region, the same levels were found as 2.4% in the Ciplak–Halileli region (Table 3). Serum Al levels were found to be nearly normal in both regions, with levels of 89% and 86% in the Kirazli and Ciplak–Halileli regions, respectively. Vitamin B_{12} levels were found to be lower than 249 pg/dL in 60.3% of those living in the Kirazli region and 70.7% of those living in the Ciplak–Halileli region.

Table 3 Serum Al, vitamin B_{12}, folic acid, and TSH levels in the study area

	Kirazli		Ciplak–Halileli	
	n	%[a]	*n*	%[a]
Aluminum normal (1.0–14.0 μg/l)	65	89.0	141	86.0
High (>14.0 μg/l)	8	11.0	23	14.0
p[b]	0.518			
Vitamin B_{12}				
249 pg/dl or less	44	60.3	116	70.7
250 pg/dl or higher	29	39.7	48	29.3
p[b]	0.113			
Folic acid				
2.9 or less	11	15.1	4	2.4
3.0–17	62	84.9	156	95.1
17.0+	0	0.0	4	2.4
p[b]	0.001			
TSH				
0.39 or less	8	11.0	18	11.0
0.4–4.0	63	86.3	139	84.8
4.01+	2	2.7	7	4.3
p[b]	0.850			

[a] Column percentage
[b] Chi-square test

Table 4 Mini-Mental State Examination score

MMSE score	Kirazli		Ciplak–Halileli	
	n	%[a]	*n*	%[a]
22 or less	24	33.3	51	31.3
23 or higher	48	66.7	112	68.7
Total	72	30.6[b]	163	69.4[b]
p[c]	0.757			

[a] Column percentage
[b] Row percentage
[c] Chi-square test

Table 5 Neuropathy in the history and examination

	Kirazli		Ciplak–Halileli	
	n	%[a]	*n*	%[a]
Neuropathy in the history				
Present	29	40.3	43	26.2
Absent	43	59.7	121	73.8
Total	72	26.2[b]	164	69.5[b]
p[c]	0.03			
Neuropathy in the examination				
Present	14	19.2	32	19.3
Absent	59	80.8	132	80.7
Total	73	30.8[b]	164	69.2[b]
p[c]	0.952			

[a] Column percentage
[b] Row percentage
[c] Chi-square test

Diagnosed chronic diseases were detected in 37.6% of the subjects and their distribution revealed that 22.4% had hypertension, 9.7% had diabetes mellitus, 6.8% had rheumatic diseases and 5.5% had renal diseases. No statistically significant difference was detected between the two regions regarding the detection of chronic diseases ($p > 0.05$).

The relationship between the MMSE scores and serum Al, TSH, vitamin B_{12}, and folic acid levels of the subjects was evaluated using Pearson correlation analysis. Only a weak positive correlation was detected between the MMSE scores and the Al levels ($r = 0.144$; $p = 0.03$). When the groups with vitamin B_{12} levels under or over 249 pg/dL were evaluated separately, a significant correlation was detected between the MMSE scores and serum Al levels; these results were, respectively, $r = 0.152$, $p = 0.057$ and $r = 0.129$, $p = 0.264$.

When the distribution of the MMSE scores between Kirazli and Ciplak–Halileli regions was studied, no statistically significant difference was detected ($p > 0.05$). However, it is worth noting that the MMSE scores were lower than 22 in 33.3% of those living in the Kirazlı region and in 31.3% of those living in the Ciplak–Halileli region.

When the distribution of the MMSE scores of the subjects was evaluated according to their primary demographic characteristics (Table 4), it was seen that the MMSE scores of 23 and higher were mostly detected in the males, in the young population, in those having an education level of high school and over, in those smoking, and in those having no chronic disease (hypertension and diabetes mellitus), and this situation was found to be significant ($p < 0.05$).

No statistically significant difference was found between the two regions regarding the physical examination findings ($p > 0.05$). However, detection of neuropathy history was relatively higher in the Kirazli region, creating a statistically significant difference ($p < 0.05$) (Table 5).

Discussion

The potential of environmental factors affecting people's health is a well-known fact since the time of Hippocrates. Today, it is scientifically accepted that many environmental factors affect human health. The potential of Al, which is found in large amounts in the nature, negatively affecting people's health caught researchers' attention, thanks to the patients having chronic renal deficiency undergoing dialysis treatment (Flaten 2001; Onur 1997).

Results of the experimental studies demonstrating the powerful neurotoxic potential of Al indicated the kind of effect it would have if taken with foods and drinking water over many years. Epidemiological studies suggested that there could be a relationship between the Al levels in drinking waters and AD (Molloy et al. 2007). Unfortunately, the backgrounds of these studies do not date back to quite early times. However, two parallel studies performed in Norway in 1986 might provide an example (Flaten 2001). In these studies, it was observed that the rate of mortality due to dementia was higher in the regions with drinking waters containing high levels of Al (Flaten 2001).

The current study was planned after detecting high levels of Al in the water resources of the Kirazli region. The primary intention was to detect the effects caused by elevated Al levels on local people. Detailed investigations were performed regarding the quality of water resources in the study area through the concentrations of some elements such as Al, As, Se, F, and Pb (Baba and Deniz 2008; Baba et al. 2008). Based on the results of this water quality monitoring program, it was detected that the Al concentration is relatively higher in the waters characterized by acidic content in the Kirazli region (Table 2). The maximum Al concentration value to be found in the drinking waters is restricted to 0.2 ppm by WHO, the US EPA, and the Turkish Ministry of Health (TC The Official Gazette 2005; WHO 2008). The raw water source was located in the middle of the Kirazli region, which had acidic characteristics and was rich in Al, and is known to be extensively used for drinking water by the local people and by the people coming from the other provinces.

No statistically significant difference was detected between the serum Al levels in the regions examined in this study. Al's primary pathway in people is thorough the digestive system. On the other hand, water has the highest potential to carry Al into people's bodies. The amount of Al directly passing into the blood from the digestive system is <1% (Flaten 2001). Al is found in small amounts in the serum, after being taken via the digestive system in normal ways (1–2 μg/l) (Flaten 2001; Ganrot 1986; Krewski et al. 2007). A large amount of Al is stored in various tissues such as bones and lungs. In healthy people, Al is normally discharged from the body through the kidneys (Flaten 2001; Ganrot 1986; Krewski et al. 2007). The serum Al level might increase up to 30 μg/l in the dialysis patients having chronic renal deficiency. In dialysis patients with chronic renal deficiency, high Al levels may result in problems such as osteomalacia and dialysis encephalopathy or dementia (Flaten 2001; Ganrot 1986; Krewski et al. 2007).

It was an expected finding that there was no remarkable increase in the Al levels in the study groups, excluding those with chronic renal deficiency and digestive system diseases requiring the use of antiacids. In our group, there were no chronic renal deficiency patients receiving dialysis treatment. Twenty-three people (9.7%) having gastritis or an ulcer did not provide any input regarding regular antiacid usage. Therefore, no difference was detected between the two study groups in their serum Al levels.

The risks connected to chronic Al exposure should not be disregarded. The development of a disease due to accumulation of Al in any organ of the body requires a continuous process lasting for many years. It has been known since 1960s that chronic Al exposure causes neuropsychological damage, encephalopathy and connected attacks, incoordination, intentional tremor, and cognitive deficits (Molloy et al. 2007; Polizzi et al. 2002). This suggests that chronic Al exposure via drinking water might constitute a significant risk factor for mild cognitive impairment (MCI), dementia, and other neurological diseases, which are not considered a serious medical or psychiatric situation in the elderly, due to having mild memory and cognitive impairments but no dementia (Flaten 2001; Petersen et al. 1999). MCI can be a prodromal phase of dementia and approximately 12% of the patients having MCI also develop dementia (Petersen et al. 1999, 2001); this rate increases up to 19.9% within 5 years (Morris et al. 2001). In their observational study carried out between 1988 and 2003, Rondeau et al. (2009) demonstrated that cognitive disorders and dementia are detected in higher rates in the people living in regions with drinking water containing high levels of Al. Moreover, in another study published in 1995, it was reported that there could be a direct relationship between the amount of Al existing in the drinking water and dementia (Nieboer et al. 1995; Polizzi et al. 2002). However, it is not easy to define this relationship clearly, because diseases like dementia and AD have multifactorial etiologies and often there is multiple complexity factors involved in this kind of study (Nieboer et al. 1995).

In terms of the MMSE score, the findings obtained in this study indicate a cognitive damage in one-third of the subjects living in the study regions. However, no statistically significant difference was detected between the Kirazlı region, which had higher amounts of Al in the drinking water, and the Ciplak–Halileli region, which had normal Al levels (Table 4). This is an interesting finding. Low vitamin B_{12} levels were also observed in the people participating from the both regions. On the other hand, folic acid levels were found to be higher in the people living in the Kirazli region compared to those living in the Ciplak–Halileli region (Table 3). In addition, the mean age of the subjects was 51.6 and 88% of them had an education level of primary school and less. All of the aforementioned factors constitute a risk for negatively affecting the MMSE scores. The findings regarding the low vitamin B_{12} levels detected in the both regions is especially interesting as a confusing factor. A weakness in the cognitive status was detected in the people living in both regions. However, this cannot be associated with Al concentration results, due to the influence of the confusing factors. The most objective way of determining the relationship between Al concentration and the cognitive status is planning an observational study with a cohort group, in which the influence of the confusing factors is minimized. However, this kind of study requires many years of observation before obtaining results. Similar studies are available in the literature. In the 8-year- and 15-year-duration observational studies carried out by Rondeau et al. in 2000 and 2009, AD was detected at a higher rate in those consuming drinking waters with an Al level over 0.1 mg/l, according to the evaluation performed by using the MMSE (Rondeau et al. 2000, 2009). The studies recommended conducting new observational surveys in order to be able to determine causes and effects of high Al levels found locally in the region on people's health.

Today, the neurotoxic effects connected to Al are known relatively better. Experiments performed on animals and studies carried out on postmortem and dialysis patients largely revealed some detrimental effects on people caused by the existence of Al concentrations in the drinking water. However, the data obtained from epidemiological studies based on drinking water are limited and controversial. In this paper, some examples from various studies in support of the detrimental effects caused by Al concentrations have been provided earlier. For example, Solfrizzi et al. (2003) reported a relationship between Al concentration and dementia; others did not report such a relationship. In other studies, the difficulty regarding the detection of the relationship between Al concentration and AD in epidemiological studies is highlighted. It is also reported that the potential of Al existence found in some foods and in medicines, as well as in drinking water, could be a confusing factor (Rogers and Simon 1999). In 2001, Flatten performed an analysis of the studies investigating the relationship between Al levels found in the drinking water versus AD and dementia diseases seen in the local people. For example; in the study carried out by McLachlan et al., the Al concentration found in the drinking water was detected to be a significant risk factor for AD (Flaten 2001; McLachlan et al. 1996). On the other hand, no relationship was detected in the study performed by Taylor et al. (Flaten 2001; Taylor et al. 1995).

Studies by Vogt (1986) demonstrated that there was a dose–response relationship between the Al concentration found in the drinking water and dementia. In the study performed by Wood et al. (1988), mental test scores of those consuming drinking water containing high Al levels were found to be relatively lower. Martyn et al. (1997) compared two regions in which the Al level of the drinking water was 0.11 mg/l in one and less than 0.01 mg/dl in the other; they reported that the relative AD risk was 1.5 times higher (Flaten 2001).

Wettstein et al. (1991) did not find any difference in terms of cognitive damage in their study group consisting of people living in Switzerland for 15 years, whose ages varied between 80 and 85. These participants were divided into two groups, based on their drinking water Al concentration of 0.10 mg/l and < 0.01 mg/l. These results are different than that of other epidemiological studies. However, the level of 0.10 mg/l, which is the highest Al level in the study, is not actually a very high level. In addition, drinking water comes from two different supplies. Due to the differences in the composition of Al level, its bioavailability might differ between different drinking water sources. In this study, the bioavailability of the Al level can be lower in the water representing the high Al level.

Another result observed in this study is the detection of a history of neuropathy. Whereas neuropathy was detected in the physical examination of 19% of the participants, no statistically significant difference was found between them (Table 5). However, a difference was detected in the neuropathy history location wise (Table 5). A history of neuropathy was detected in 40% of the participants living in the Kirazli region and in 26% of those living in the Ciplak–Halileli region.

The neurotoxic effects of Al levels suggest a neuropathic effect, in addition to cognitive effects and dementia. Uremic neuropathy, which is observed in patients with chronic renal deficiency, was defined by Kussmaul for the first time in 1863 (Burn and Bates 1998). The main neurological manifestations of uremia include encephalopathy, neuropathy that can affect cranial, peripheral, and autonomic nerves, and proximal myopathy. With the active administration of dialysis in uremic patients, complications connected to dialysis also started to be seen. Chronic dialysis is associated with three main neurological syndromes:

1. The disequilibrium syndrome, usually seen in the first few hemodialysis sessions and prevented by starting dialysis with a low dose and progressively increasing the dialysis dose in subsequent dialysis sessions.
2. Dialysis dementia, which results from Al overloading and is prevented by reducing exposure of the dialysis patients to Al.
3. Nerve entrapment, particularly carpal tunnel syndrome, which is caused by β_2-microglobulin amyloidosis and might be prevented by the use of high-flux dialyzers, which provide relatively high clearance for β_2-microglobulin or by daily hemodialysis (Tzamaloukas and Agaba 2004).

The pathogenesis of neuropathy and encephalopathy in patients with renal failure remains unknown. Possible factors include Al intoxication, in particular (Sperschneider et al. 1982). The relationship between Al level and neuropathy is mostly backed up by the data obtained from uremic patients undergoing dialysis treatment. However, uremia alone can cause neuropathy in these patients, making it difficult to detect exclusive effects of Al level. As a result, a multifactorial interaction is effective in the formation of neuropathy. In the regions examined, it was observed that there was a vitamin B_{12} deficiency in both regions, whereas folic acid deficiency, hypertension (22%), and diabetes (10%) were detected in the Kirazli region. All of the aforementioned factors stand out as a complexity factor for the neuropathy history. Both regions have similarities in terms of the other variations, except for the folic acid levels. This indicates that the reason underlying the liability of neuropathy in the Kirazli region can be chronic Al exposure. More objective evaluations can be made with additional observational surveys.

Although different results are reported in different epidemiological studies, the data at hand suggest that the Al concentration found in high rates in the drinking water might have negative effects on people's health. This study does not present objective evidence demonstrating that the people living in the Kirazli region were affected by the Al level. However, findings regarding the high rate of cognitive disorders found in the people living in the region and neuropathy history, which was detected as higher in the Kirazli region, increase our suspicions for being caused by the existence of Al in the drinking water, in spite of the high rate of vitamin B_{12} deficiency. The way to justify these suspicions based on powerful evidence is by conducting additional observational studies.

Conclusions

Evaluation of the data obtained in the scope of this study indicates that further monitoring studies should be planned to allow more objective observations of the problems to be made, especially the existence of Al in the drinking water. Another interesting point to consider is that the people living in the Kirazli region still continue consuming water containing high Al concentrations. In general, there are purification technologies regarding the elimination of Al in the water supplies. However, purification technologies require electrical power. People living in the region cannot use such techniques due to economic reasons. The carbonated water within the alluvium deposits found in the peninsula could be used as a source of water for the region's population to this end.

It is important to monitor, for drinking purposes, the quality of water exposed at rock–water interactions in alteration zones. This kind of water have been seen in many countries. This water has higher acidity and more trace element concentrations. The levels of these elements are found to exceed the maximum allowable limits set by national and international standards for the drinking water quality. This finding demonstrates the necessity for conducting detailed research on human health effects of consuming such waters.

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