International Journal of Preventive Medicine

Original Article Open Access

Association between Aluminum and Silicon Concentrations in Isfahan Drinking Water and Their Health Risk Assessments

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How to cite this article: Pourgheysari H, Hajizadeh Y, Tarrahi MJ, Ebrahimi A. Association between aluminum and silicon concentrations in Isfahan drinking water and their health risk assessments. Int J Prev Med 2015;6:111.

ABSTRACT

Background: High concentrations of elements such as aluminum (Al) and silicon (Si) in drinking water can affect human health. It is suggested that high daily intake of Al is associated with increased risk of neurodegenerative disorders. Si, as an antidote of Al, may decrease Al bioavailability. The study was conducted to estimate Al and Si concentration and correlation in water and evaluate their health risk.

Methods: In this cross-sectional study, water samples were collected from 20 points of water distribution system and the water treatment plant of Isfahan in spring and summer. Samples were analyzed using DR-5000. The health risk was evaluated via calculating chronic daily intake (CDI) and hazard index (HI).

Results: Significant negative correlation was documented between Al and Si ($R = -0.482$, $P = 0.037$ in spring, and $R = -0.452$, $P = 0.049$ in summer). These values were approximately similar in all types of Al and Si. The amounts of CDI for Al in spring and summer were 6.67E-04 and 0.002 mg/kg/day, respectively. The Al HI values were below 1 in both seasons.

Conclusions: The significant correlation between Al and Si concentrations suggests that Si can eliminate Al in water, and probably it might do the same in the body. The health risk of Al intake from tap water was negligible, it was assessed in an acceptable range with an HI value of less than the standard levels. The health risk of Si remained unknown due to lack of information regarding its toxicity and adverse health effects.

Keywords: Aluminum, chronic daily intake, correlation, hazard index, silicon

Access this article online	
Quick Response Code:	Website: www.ijpvmjournal.net / www.ijpm.ir
	DOI: 10.4103/2008-7802.169644

INTRODUCTION

Drinking water contains various compounds, heavy metals and biological matters that can transfer to the body and cause adverse health effects.[1,2] Among all these substances, aluminum (Al) which is widely spread throughout the nature is one of the nonessential elements for human beings.[3,4] Several studies have shown that acid rain can reduce the pH in soil, resulting in an increase in

Al mobility and its transmission to the groundwater as well as its bioavailability through the food chain.[4,5] The elevated amount of Al in tissues is the result of its intake via diet and decrease of renal excretion, which seems to be a reason of neurodegenerative cerebral disorders such as Alzheimer. Extensive research has been conducted to investigate a possible link between Al and Alzheimer's disease. Animals with high intake of Al develop both symptoms and brain lesions, which are similar to those found in Alzheimer's disease.[4,6,7] Some studies have suggested that silicon (Si) is a natural antidote to the Al^{3+} that may decrease the bioavailability of Al by hindering its uptake through the gastrointestinal tract and by impeding its reabsorption.[8-10] The main sources of Si via foods are cereal products, unrefined grains, and root vegetables; however, its availability in meat, milk, and beer is higher than the others.[11] Studies have suggested that Si is essential in rats and chicks' diet, and its insufficiency is associated with growth defects, especially with bone and cartilage formation, whereas, a study in human has shown that ingestion of a Si supplement resulted in an increase in bone mass.[10,12]

Different countries have regulated various guidelines for Al content in drinking water. Dissolved Al concentrations in waters with near-neutral pH values usually range from 0.001 to 0.05 mg/l but in acidic waters or water with high organic matter rise to 0.5–1 mg/l.[13] The UK has set 0.2 mg/l of Al for small water treatment facilities and 0.1 mg/l for the larger ones as a guideline for preventing turbid and color but not as a healthy level.[14] EPA, EU, Finland, and Australian guideline for Al concentration in drinking water is 0.2 mg/l.[15-17] The UNEP and Canada have set Al concentration by 0.1 mg/l.[18,19] According to the Australian drinking water guideline, dissolved silica (SiO_2) can range from 0.6 mg/l in some surface waters to 110 mg/l in ground waters. However, to minimize an undesirable scale build-up on surfaces, silica should not exceed 80 mg/l in drinking water.[16] There is no special regulation for Al and silica concentrations in drinking water in Iran. This research was done to investigate the correlation between soluble Al and Si concentration in the water with respect to the water quality parameters in the Isfahan water distribution system. Estimation of the health risk of Al via drinking water intake was also investigated in this study.

METHODS

This cross-sectional descriptive study was conducted to evaluate the correlation between Al and Si with regard to some other water quality parameters such as electrical conductivity (EC), pH, total dissolved solids (TDS), and turbidity in Isfahan water distribution system in 2013. Isfahan receives its drinking water from a water treatment plant, which treats surface water taken from a dam far from the city. However, in hot seasons with low precipitation and high water consumption, the scarcity is compensated by direct pumping of good quality well water to the pipelines or reservoirs. Therefore, sampling was carried out in two seasons: Spring as a wet season and summer as a dry season. It was expected that raining in the spring and mixing well water with surface water in the summer might affect the water quality. Twenty sampling points were chosen in such a way to cover all the low, medium, and high dense area of the city. The sampling points are presented in Table 1. GPS illustrations of the sampling points are shown in Figure 1. All the samples were taken from tap water of public access facilities and private residences among the both seasons. Moreover, two samples, one from the influent and other from the effluent of the water treatment plant were also taken in each sampling times to evaluate the effects of water distribution system on water quality. The concentrations of Al and Si were determined using a spectrophotometer (DR-5000, Hach Lange, USA). Eriochrome cyanine R method for Al analysis and low range heteropoly blue method for Si analysis were applied. The analyses of some samples were carried out in duplicate to achieve precise results. The correlation between above-mentioned and Si and Al concentrations, and the association between Al and Si were evaluated by SPSS software using the Pearson correlation test. The concentration of Al and Si in

Table 1: Details of sampling points

Location	X position	Y position
Chahar Bagh-e Bala	562,452	3,610,270
Shafagh Ave.	554,854	3,608,712
Simin Crossroad	558,850	3,609,728
Felezi Bridge	561,409	3,612,084
Emam Khomeyni Street	559,686	3,616,603
First Robat Ave.	561,237	3,616,234
Chamran Ave.	562,917	3,617,490
Razmandegan Ave.	561,867	3,619,078
Gharazi Hospital	563,849	3,620,975
Dolat Abad (Golestan Ave.)	566,022	3,620,524
Ghods Square	564,721	3,615,820
Jey Ave.	565,961	3,614,189
Khorasgan University	573,082	3,611,916
Bahman 22nd Ave.	566,299	3,612,142
Ghaem Magham Ave.	566,159	3,610,157
Saremiye Ave.	560,315	3,613,269
Sepahan Shahr	562,873	3,601,937
Baharestan	570,542	3,593,594
Hezar Jarib Ave.	572,132	3,594,182
Isfahan water treatment plant	572,132	3,594,182

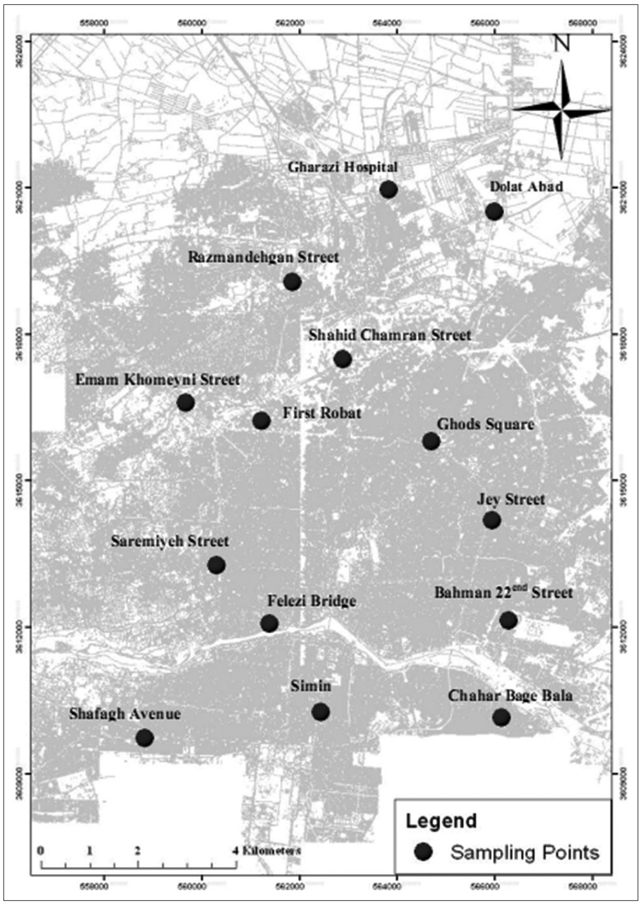

Figure 1: Location of Isfahan drinking water network sampling points

different seasons was also illustrated by Geographical Information System (GIS) software version 10. Amount of chronic daily intake (CDI) was calculated using Eq. (1).[20]

$$CDI = (C \times DI)/BW. \quad (1)$$

Where, CDI (mg/kg/day), C is the Al concentration in water (mg/l), DI is an average daily intake rate of Al from drinking water (2 l/day) taken from study of Dzulfakar *et al.*,[21] and BW is adults body weight based on the Iranian average body weight (60 kg).[2]

For noncarcinogenic health effects due to Al in drinking water, the hazard index (HI) was calculated using Eq. (2). Amount of HI <1 shows no health risk to consumers.[20,21]

$$HI = CDI/RfD. \quad (2)$$

Where RfD is reference dose and is 7 mg/kg/day for Al in water.[21]

RESULTS

As the experiments were carried out during two seasons, the results for each season are presented separately. Table 2 shows the results of correlation analysis

Table 2: Correlation analysis between Si and Al species

Parameter	Spring		Summer	
	SiO_2	Si	SiO_2	Si
Al^{3+}				
R	−0.481*	−0.482*	−0.452†	−0.452†
P	0.037	0.037	0.049	0.049
Al_2O_3				
R	−0.490*	−0.491*	−0.455†	−0.455†
P	0.033	0.033	0.051	0.051

*Correlation is significant at 0.01 level (two-tailed), †Correlation is significant at 0.05 level (two-tailed), Total number of samples in each season is 20. *R*=Pearson's correlation index, *P*=Significance, Si=Silicon, Al=Aluminum, SiO_2=Silicon dioxide, Al^{3+}=Aluminum ion, Al_2O_3=Aluminum oxide

between Al and Si species determined in water samples in summer and spring. Table 3 represents the results of correlation test that was carried out between some other water quality parameters (pH, EC, TDS, and turbidity) and Si and Al species concentrations in the two seasons. The correlation index (*r*) and *P* value (*P*) between each parameter and Al and Si were outlined in these tables.

The descriptive results of the Al and Si concentrations and the other water quality parameters in the samples are presented in Table 4, which were collected throughout the Isfahan water distribution network during the study period. Figure 2 shows Al and Si concentrations in discrete sampling points. Concentrations of elements are depicted using light to dark colors, representing lower to higher concentrations, respectively. As shown in Figure 2a, in the spring, the Al concentration was high in the southeast and there is a decline toward the northwest. According to Figure 2b, the concentration of Si in the spring has fewer fluctuations except in some points that had a higher concentration of Si. As shown in Figure 2c and d, in the summer, in various locations the concentrations of the elements were changed and not followed an especial pattern but again showed a negative correlation between Al and Si.

Analysis of Al and Si concentrations in the influent and effluent of the water treatment plant showed that the concentration of Al in the spring for both raw water and treated water was 0.01 mg/l. In the summer, the result of raw water was missed, so just the concentration of Al in the treated water was presented amounting to 0.06 mg/l. The concentration of Si in the spring in the raw and treated water was 7.22 and 5.98 mg/l, respectively; whereas its concentration in the summer in the treated water was reduced to 0.11 mg/l.

The values of CDI calculated for Al in spring and summer were 6.67E-04 and 0.002 mg/kg/day, respectively. The estimated HI calculated by CDI values were 9.52E-05 and 2.86E-04 in spring and summer, respectively. The HI values were below 1 in both the seasons.

Table 3: Correlation analysis between water quality parameters and Si and Al species in Isfahan drinking water in spring and summer

Parameter	pH		EC		TDS		Turbidity	
	Spring	Summer	Spring	Summer	Spring	Summer	Spring	Summer
SiO_2								
R	−0.325	−0.017	0.851*	0.224	0.851*	0.224	0.544*	0.321
P	0.174	0.946	0.000	0.356	0.000	0.356	0.016	0.180
Si								
R	−0.322	−0.016	0.852*	0.225	0.852*	0.225	0.543*	0.323
P	0.179	0.947	0.000	0.354	0.000	0.354	0.016	0.178
Al^{3+}								
R	0.411	0.228	−0.673*	−0.407	−0.673*	−0.407	−0.206	−0.244
P	0.080	0.347	0.002	0.084	0.002	0.084	0.398	0.314
Al_2O_3								
R	0.425	0.221	−0.678*	−0.407	−0.678*	−0.407	−0.222	−0.242
P	0.070	0.363	0.001	0.084	0.001	0.084	0.360	0.319

*Correlation is significant at 0.01 level (two-tailed). *R*=Pearson's correlation index, *P*=Significance, EC=Electrical conductivity, TDS=Total dissolved solids, Si=Silicon, Al=Aluminum, SiO_2=Silicon dioxide, Al^{3+}=Aluminum ion, Al_2O_3=Aluminum oxide

Table 4: The descriptive results of Al, Si, and other quality parameters in Isfahan drinking water in spring and summer

Parameter	Minimum		Maximum		Mean		SD	
	Spring	Summer	Spring	Summer	Spring	Summer	Spring	Summer
Conductivity*	354	342	1010	795	599	441	185	112
pH	6.90	6.80	7.80	7.40	7.33	7.03	0.27	0.19
Turbidity	0.18	0.41	0.73	1.05	0.32	0.61	0.17	0.18
TDS (mg/l)	175	169	500	394	296	219	91	55
$Al^{3+\dagger}$	0.01	0.03	0.03	0.08	0.02	0.06	0.01	0.01
$Si^{\dagger}$	1.84	0.93	6.31	2.71	2.97	1.52	0.97	0.46

*The unit is µs/cm, †The concentration describes in mg/l. SD=Standard deviation, Al=Aluminum, Si=Silicon, Al^{3+}=Aluminum ion, TDS=Total dissolved solids

DISCUSSION

Results from this descriptive study support the idea of an existing correlation between Al and Si in drinking water. This is in agreement with previous studies that have been conducted on Al and Si cycle in the ocean,[22] and also on Al species in drinking water.[23,24] The only exception was Al_2O_3, which did not reveal any correlation with Si species just in the summer ($P > 0.05$). Moreover, the negative correlation means that with the increase in the Si concentration, the Al amount decreased. The correlation between Al and Si species was in a relatively constant amount in both seasons. This negative correlation can also be inferred from Figure 2, which shows that when the Al concentration was high, Si was in the minimum range. It also shows that the correlations between Al and Si were different between the two seasons, probably due to the fluctuation in Al and Si concentrations.

Moreover, the negative correlation is an emphasis on the study of Davenward *et al.*, where they suggested that Si rich mineral water could be a treatment for Alzheimer disease as it may eliminate the aggregated Al in tissues by urinary excretion.[8]

Comparison between Figure 2a and b and fewer fluctuations in Al concentrations, and in Figure 2c and d with a different pattern in Si concentrations gives the impression that other sources of water was fed into the distribution system. Nevertheless, it should be emphasized that the correlation between Al and Si is clear in the two studied seasons. It can be also realized from Table 3 and presented correlations that some water quality parameters affected the concentration of both Si and Al in water. Other parameters such as climate change during different seasons and the characteristics of well water injected to the distribution system can also affect these elements' concentration.

There was some paradox in the results during different seasons. The effect of water quality parameters such as EC, TDS, and turbidity values on Si and Al concentrations was noticeable in the spring. The information about the amount of parameters in spring and summer is shown in Table 4. According to the results, range of the pH in the distribution system was not so widespread. The correlation between Si species and water quality parameters [Table 3] showed a negative relationship between Si and pH. It implies that with increasing pH,

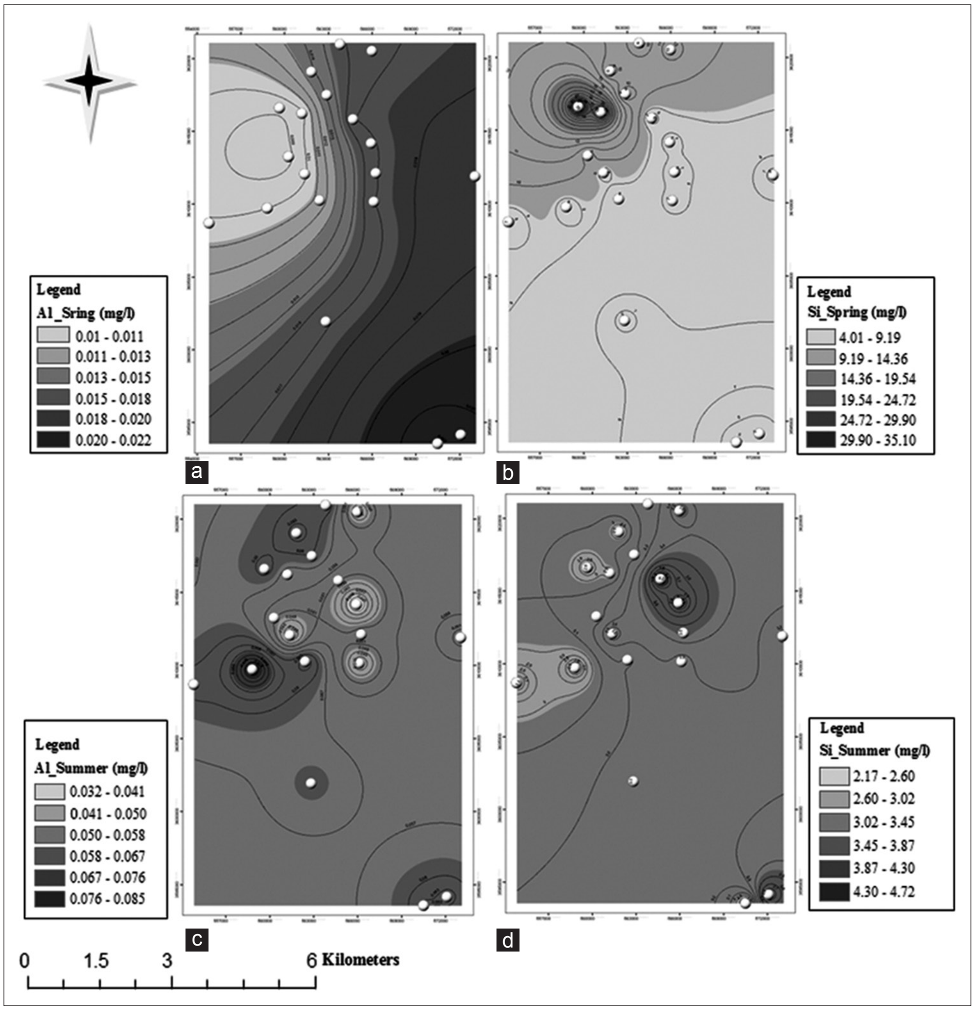

Figure 2: Concentration of aluminum and silicon in the sampling seasons: (a) Aluminum concentration in spring, (b) silicon concentration in spring, (c) aluminum concentration in summer, and (d) silicon concentration in summer

the concentration of Si was decreased. On the contrary, the correlation between pH and Al species was positive which is consistent with the results of some recent studies,[5,23] however, for both Al and Si the evaluated correlation with pH was not significant ($P > 0.05$).

The correlation between EC and TDS was significant for Si during the spring but that for Al was negative and not significant at all. The positive correlation between Si, EC, and TDS relies on this fact that by increasing the EC and TDS levels in water, the concentration of Si species increases. This supports the study of House *et al*. who stated that the presence of finer sediments affects the Si concentration in a positive manner.[1] Contrariwise, during the summer there is no high stream flow, thus, there would not be considerable release of Si from the sediments. Beside this, in the summer, substantial amount of well water is added to the distribution system which increases the amount of TDS and EC. In overall, some fluctuations occurred during the spring were moderated in the summer which can be attributed to a constant characteristics of the feed water during this season.

As shown in Table 4, the maximum amount of turbidity among the spring was higher than that in the summer, however, the difference between their medium in two seasons was not meaningful. The correlation between turbidity and Si showed a significant positive manner, whereas a negative correlation between Al and turbidity was observed. This suggests that by an increase in turbidity, the amount of Al was decreased. These findings support the hypothesis of existing negative correlation between Al and Si concentrations in water bodies. However, complying with the same reason described for TDS and EC, there was no significant correlation between Al or Si concentrations and turbidity in the summer.

Analysis of Al and Si concentrations in the influent and effluent of the water treatment plant suggested that as the Al concentration rises, the concentration of Si drops. The results also did not show a significant difference between Al in the treatment plant and the distribution system. However, the mean concentration of Si in the distribution system was higher than that in the treatment plant effluent. This can be because of released pipeline material and the composition of the auxiliary water feeding into the distribution system. However, it should be noted that there were some limitations in sampling from water treatment plant because of security issues.

The results showed that in the spring the average concentration of Al in the water distribution network had a significant difference with guidelines and lower than that ($P < 0.001$). In the summer, with a significant difference ($P = 0.025$), the concentration of Al was smaller than the guideline as well.

The HI values are below 1 in both seasons which imply that no chronic health effects are likely to occur from Al in drinking water in the Isfahan water distribution system. However, health effects due to intakes of low concentration of Al over time cannot be ruled out, as there are currently few studies addressing this issue. As we could not find any especial standard related to human health for Si, the amount of RFD related to Si was not calculated. The health risk of Si intake via drinking water was not calculated as well due to the lack of health risk information and regulatory guideline. On the basis of these findings, we cannot imply that there is an effect on human health by Al and Si intake via tap water. Further studies are needed to investigate the actual mechanism of link between Al and Si levels and to evaluate other relevant risk factors such as their intake from foods, specifically using multivariate statistical models, and specific disease outcomes.

CONCLUSIONS

The study points out that Al concentration in drinking water is associated with Si contents. Presence of both Al and Si is depended on water quality parameters such as EC, pH, and turbidity. These parameters showed a different correlation with Al and Si. The only significant parameter in this study was pH that showed a negative relationship with Si and positive relationship with Al. The results did not show the same correlation in the two seasons which can be the result of changes in climate, feed water source into the distribution system, and may be some other parameters that should come into account in future studies. The correlation shows that high Si content can eliminate Al in water. Regarding this fact, it can be suggested that further studies should be done to investigate whether Si rich water is efficient to prevent Al aggregation in different tissues of the body.

According to the Al HI, it is recommended that the experiment should take place in more frequent series during different seasons with respect to the water quality parameters and water sources to obtain more precise results. Further survey should be done to investigate possible health risk related to Si intake, and more *in-vivo* investigations should take place to determine the relations between Si and human health.

ACKNOWLEDGEMENTS

The authors aim to acknowledge the Department of Environmental Health Engineering and the Student Research Centre, School of Health in Isfahan University of Medical Sciences, for financial support and the laboratory staff of the department for their technical support in this research project no. 191145.

Received: 11 Nov 14 **Accepted:** 25 Jul 15
Published: 12 Nov 15

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Source of Support: Isfahan University of Medical Sciences, **Conflict of Interest:** None declared.