Annals of Journal of Environmental Science and Toxicology

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Dates: Received: 27 November, 2015; **Accepted:** 04 January, 2016; **Published:** 05 January, 2016

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ISSN: 2641-2969

www.peertechz.com

Keywords: Boron; Drinking water; Volcanic area; THQ; EDI

Research Article

Boron Levels in Drinking Water Sources from the Volcanic Area of Sicily (South Italy): Risk Evaluation of Developing Chronic Systemic Effects

Abstract

Short- and long-term oral exposures to boric acid or borax demonstrated boron toxicity in reproductive system. European Union standard of boron in drinking water has a maximum allowable concentration of 1 mg/L, but in Sicily (south Italy) there are often higher concentrations.

Accordingly, the main objectives of this study, the first of its kind in the south Italy, were (1) to monitor the boron levels in drinking water sources from Mt. Etna, and (2) to estimate the daily intake (EDI) and the Target Hazard Quotient (THQ) in adult population to evaluate the risk of developing chronic systemic effects due to drinking boron intake.

We divided the study area into five sectors. Mt. Etna water sources, were collected from 2000 to 2014 and were analyzed by inductively coupled plasma - optical emission spectrometry (ICP-OES). We found boron mean values ranged from 0.199 to 0.863 mg/L with minimum and maximum concentrations of 0.010 and 2.620 mg/L, respectively. Adult EDI concentration was between 0.004 and 0.020 mg/Kg day, thus below the Reference Daily Dose (RfDo) suggested by the Environmental Protection Agency (EPA). THQ always resulted below the level of risk, indicating no risk to develop chronic systemic effects due to drinking boron intake during the lifetime.

Introduction

Boron is a ubiquitous chemical element widely distributed in nature. Both natural and anthropogenic factors can lead to the release of boron in air, water and soil [1].

The boron dissolved in Mediterranean region groundwater is generally geogenic, being related to hydrothermal or saline water sources, water-rock interaction and seawater intrusion [2,3]. Anthropogenic factors can also lead to the release of boron into air, water or soil because it is used in a variety of products including glass and glass products, leather, cleaning products, cosmetics, agrochemicals, insecticides, flame retardants and corrosion inhibitors [1,4], so that, contamination of boron showing a positive trend in the environment [5].

Short- and long-term oral exposures to boric acid or borax demonstrated that the male reproductive tract was a consistent target of boron toxicity in laboratory animals [6]. A recent investigation on boron workers showed that boron exposure might cause the delay in theirs wife pregnancy and a decrease in live birth [7]. Sexual chromosomes test (FISH test) showed that chromosome ratio of Y:X significantly decrease due to boron exposure [8].

In view of the accurate assessment of human health under long-term exposure of boron, the investigation on the environment boron levels is much of significance. In humans, boron exposure occurs primarily through oral intake of food and drinking water. Intakes of boron for humans are been expected to be 0.44 μg/day from ambient air, 0.2-0.6 mg/day from drinking water and 1.2 mg/day from the diet [9].

Previous studies performed with experimental animals indicated that over 90% of boric acid and borax administrated could be absorbed through the gastrointestinal and respiratory tracts [10-12].

In most parts of the world, the concentration range of boron in drinking water is between 0.1-0.3 mg/L [6]. The limit values suggested for boron in drinking water from WHO and UE are 0.5 and 1 mg/L respectively [6,13]. Recently, WHO has suggested to convert the current limit acknowledged by EC to 2.4 mg/L [14]. Mount Etna host a major aquifer that provides drinking water to more than 750.000 inhabitants and irrigation to large agricultural areas nearby. Water from this aquifer and the volcanic soil undergoes a magmatic-type interaction, in which excess CO_2 in volcanic gas leads to acidification of water and to leaching of chemicals from the basalt rock, especially on the lower South-South-Western and Eastern flanks of the volcano. Various elements and chemicals (HCO_3, solphates, calcium, fluoride, chloride, magnesium, boron, manganese, iron, vanadium and their salts) are often higher in water samples from various sources of this volcanic aquifer [15].

Thus, the present study aimed to monitor the boron levels in drinking water sources of the volcanic area of eastern Sicily (south

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Italy) and to estimate the daily intake (EDI) and the Target Hazard Quotient (THQ) in adult population to evaluate the risk of developing chronic systemic effects due to drinking boron intake.

Material and Methods

The study area includes 29 municipalities (Figure 1) of the eastern Sicily located on Mt. Etna. We divided this area in five sectors around the main crater of the volcano (South West – SW; South – S; South East – SE; North West – NW; North East – NE).

Drinking water samples were collected, from 2000 to 2014, according to the procedure required by official instructions of the Environmental Protection Agency and the Italian National Research Council [16]. Drinking water samples including groundwater, tap water and springs water.

Boron was detected by inductively coupled plasma - optical emission spectrometry ICP-OES Optima 2000 DV (Perkin-Elmer, USA), according to the method UNI EN ISO 11885:2009, with a method detection limit (MDL) calculated of 0.01 mg/L.

Boron levels were expressed as median (IQR). A Kruskal-Wallis non-parametric method was been applied to test equality of population medians among groups with statistical significance set at $p<0.05$. Statistical analysis was performed by Statistical Package for Social Sciences (SPSS) software (SPSS Inc., Chicago, IL, USA).

The estimated daily intake of B (mg/Kg/day) due to Etna groundwater exposure was calculated using the equation:

$$EDI = (IR \times C) / BW$$

Where, IR is the Ingestion Rate, assuming it as 2L-day for adults, C is the metal concentration (mg/L), and BW is the body weight, assuming it as 70 Kg in adults [17].

The health risk from drinking water sources consumption by local inhabitants was assessed based on the target hazard quotient (THQ). The THQ is a ratio between the dose of a pollutant and the reference dose level. If the ratio is less than 1 the exposed population is unlikely to experience obvious adverse effects.

The method of estimating risk using THQ is provided in the US EPA Region III risk-based concentration table (US-EPA, 2007) and it is described by the following equation:

$$THQ = [(EFr \times ED \times IR \times MC)/(RfD \times BW \times AT)] \times 10^{-3}$$

Where: EFr is exposure frequency (365 days/year); ED is the exposure duration (70 years in adults); IR is the ingestion rate (2 L for adults); C is boron concentration in drinking water (mg/L); RfD is the oral reference dose (0.2 mg/Kg day); BW is the average body weight (adult, 70 kg); AT is averaging time for non-carcinogens (365 days/ year x number of exposure years, assuming 70 years for adults).

Results and Discussion

Boron median values ranged from 0.199 to 0.863 mg/L in the five sectors monitored with minimum and maximum concentrations of 0.010 and 2.620 mg/L, respectively. As shown in Table 1 we observed that the EDI of boron in adult population was below the reference dose (0.2 mg/Kg day) suggested by EPA and THQ below 1. The higher ingestion dose was measured in the volcanic sector S, followed by the SW and SE sectors, where the EDI recorded represent respectively the 10.0, 7.5 and 7.0% of the total RfDo.

Kruskal-Wallis test revealed significant different concentrations among sectors analyzed ($p<0.001$). In particular, concentrations in the S sector is significant higher of all other sectors and SW and SE concentrations are also significant higher of the NW ones (Table 1, Figure 2).

The main results found were (1) EDI of boron never exceed the reference dose, (2) THQ values in each sector were within safe limits (THQ <1), suggesting that ingestion of drinking water may not be a health risk.

Some experimental studies report data on the positive effects of low doses and negative effects of high doses of boron on development [18-20]. The mechanisms underlying these effects and available data on dose-response relationships are uncertain [21,22]. The limited oral exposure studies performed to date, do not allow drawing any certain conclusion on toxic oral reference dose and the Environmental Protection Agency has calculated a reference dose for boron oral intake (0.2 mg/Kg/day) based only on decreased fetal weight [23].

It was been observed that high doses of boron exposure may have an effect on acute and chronic toxicity to testis and reproductive functions. On the other hand, low doses of boron have a positive effect

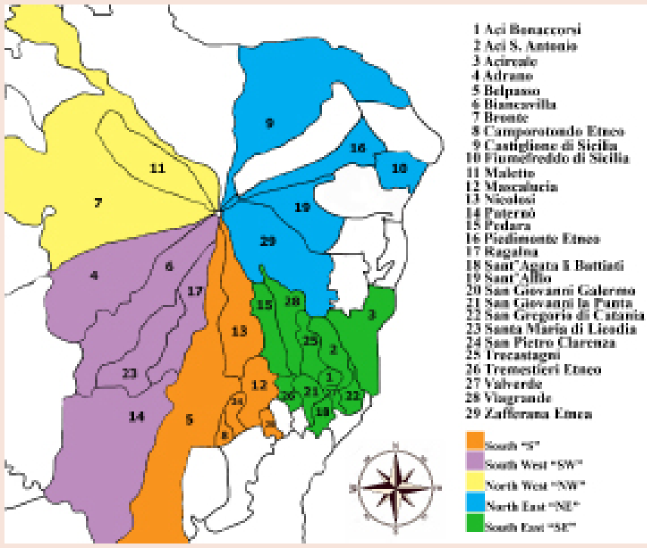

Figure 1: Distribution map of the five sectors analyzed, including each municipality with respectively boundaries.

Table 1: Descriptive statistic, exposure daily intake (EDI) and target hazard quotient (THQ) from each sector of Mt. Etna.

Sectors	n.	Median B mg/L	IQR	EDI mg/Kg day	THQ
SW	122	0.515	0.24 - 0.63	0.015	0.074
S	137	0.712	0.49 - 1.21	0.020	0.102
SE	93	0.480	0.32 - 0.58	0.014	0.069
NE	49	0.213	0.15 - 0.57	0.006	0.030
NW	64	0.126	0.09 - 0.21	0.004	0.018

SW: South West, S: South, SE: South East, NE: North East, NW: North West.

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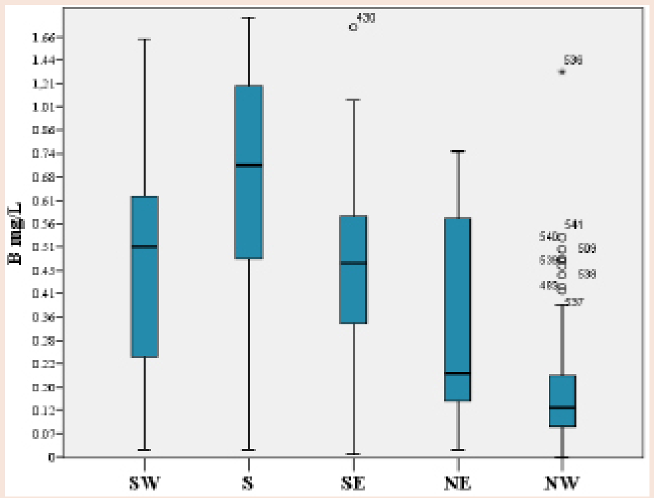

Figure 2: Distribution of boron concentrations in drinking water sources by sectors.

on the healing of wounds and cerebral functions and by affecting calcium metabolism serves to activate bone and mineral metabolism. Furthermore, it has anti-osteoporotic, anti-inflammatory, anti-coagulating, anti-neoplastic and hypolipemic effect [24-31].

Geological factors such as rock weathering and soil leaching may cause high boron level in ground water. Most of boron concentrations in freshwater are less than 0.1 mg/L; however, in areas with boron rich soils, boron concentration in surface water is up to 26 mg/L [6]. Boron levels in surface water have been investigated in detail in different countries of Europe [4]. Comparison of boron concentrations in surface water sources from different countries including Asia, Africa, America, and Europe showed that Portugal has the highest mean of boron levels in surface water and Argentina has the highest mean of boron concentrations in ground water. In the dry areas of Chile, boron concentrations both in surface and ground waters are much higher than those in other regions [32].

Our findings indicate that boron levels in drinking water sources of main towns of Eastern Sicily are generally at the same level or slightly lower than those in most of other countries in the world [32]. Our investigations highlighted that, in the volcanic area of Sicily drinking water sources, the boron concentration was mainly below the European Union standard (1 mg/L) and in some cases above.

Conclusion

The presence of boron in drinking water sources of Eastern Sicily appears to be of natural origin. Considering that chemical characteristics of water sources from volcanic areas depends on the different chemical composition of the lava rocks crossed by groundwater supply, the significant higher concentration of boron detected on the southern slope, compared with the other sectors analyzed, suggests the presence of volcanic rocks rich in boron on this side and therefore, it allows the leaching of boron into the water.

This is the first study that has investigated the boron levels in a volcanic area which also focused on EDI and THQ. Inhabitants of the volcanic area in eastern Sicily are habitually exposed to chronic boron intake through longterm use of local water, for drinking or food preparation, and consumption of locally grown food (fresh vegetables, fruit and wine) cultivated in the area of study.

To sum up, this study area is suitable for future epidemiological research, carrying out health impact studies with medical examination by interview and enabling a better cost/risk analysis for developing feasible management solutions.

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