Original Research Article

Concentration of arsenic in drinking water in Bandar Abbas city and quantitative risk assessment

Yadolah Fakhri¹, Ghazaleh langarizadeh², Bigard Moradi³, Yahya Zandsalimi⁴, Leila rasouli amirhajeloo⁵, Saeedeh Jafarzadeh⁶, Athena Rafieepour⁷ and Maryam Mirzaei⁸*

¹Social Determinants in Health Promotion Research Center, Hormozgan University of Medical Sciences, Bandar Abbas, Iran.
²Food and Drugs Research Center, Bam University of Medical Sciences, Bam, Iran
³Department of Health Public, Kermanshah University of Medical Sciences, Kermanshah, Iran
⁴Environmental Health Research Center, Kurdistan University of Medical Sciences, Sanandaj, Iran
⁵Department of Environmental Health Engineering, School of Public Health, Qom University of Medical Sciences, Qom, Iran.
⁶Research Center for Non-Communicable Disease, Fasa University of Medical Sciences, Fasa, Iran
⁷Student's Research Committee, Shahid Beheshti University of Medical sciences, Tehran, Iran
⁸Research Center for Non-Communicable Disease, M.Sc of Critical Care Nursing, Jahrom University of Medical Sciences, Jahrom, Iran
*Corresponding author

ABSTRACT

The presence of heavy metals like arsenic in drinking water sources can endanger human health because of being toxic and carcinogenic. In this study, 432 samples of eight brands of bottled water consumed during the summer and winter in 2013 were collected from the city of Bandar Abbas. Concentration of arsenic were measured by atomic absorption device, spectrophotometer DR2800 model and according to the method Silver Diethyldithiocarbamate. CDI, R and HQ for adult men, adult women, and children was evaluated and calculated through the EPA and WHO equations. Mean and range of arsenic are 5.67±0.73 µg/l and 0.9-16.3 µg/l. The mean arsenic concentration is below WHO and EPA standard (10 μg/l). The order arsenic concentration in bottled water brands is almost BW7> BW8> BW6>BW1>BW5 > BW2 >BW3> BW4. CDI, R and HQ in children is 2 times more than adult men and women (p value<0.05). Carcinogenic risk of arsenic for children (67E-5), adult men (30E-5) and adult women (28E-5) is more than acceptable R level of EPA (1E-6) and WHO (1E-4). Hence, all age groups are at carcinogen risk range. Since HQ for adult men (0.67) and adult women (0.62) is less than 1 and for children (1.52) is more than 1, hence, adult men and women are in non-carcinogenic risks area and children are in non-safe area.

Keywords
Arsenic, Bottled water, Carcinogenicity risk, Non-carcinogenic risk

Introduction

Heavy metals have properties such as biological accumulation, toxicity and environmental sustainability.[1] In recent years, the presence of heavy metals such as arsenic (As), cadmium (Cd), mercury (Hg), lead (Pb), nickel (Ni) and chromium (Cr) in
drinking water has become an environmental and health concern [4-2]. Entering heavy metals into water resources can be from natural processes such as erosion or caused by human activities, such as municipal, industrial or agricultural sewage discharges [5]. Heavy metals exist naturally in small amounts in water. Many of these elements have a dual role in the human body [6]. Even they are harmless at low concentrations and in some cases even beneficial to health, but they can be hazardous to human health at higher concentrations than the standard level [8,7]. Epidemiological studies show that there is a significant relationship between tooth decay, heart disease, kidney disorders, neurological disorders and cancers and heavy metals [9-11]. Arsenic entry into the body caused by eating and drinking in a long term can cause skin cancer, Lung cancer, bladder, liver and kidney cancer [12-13]. Epidemiological study by Chen et al show with increase arsenic in drinking water increase A very important factor in causing black foot disease is drinking water contaminated with arsenic [14]. Also, entering arsenic for a long time can cause skin lesions in people (50 µg/l ≥) [15]. The World Health Organization (WHO) is recommended 10 µg/l guidelines level for arsenic [16]. Also Recently United States Environmental Protection Agency (EPA) adopted the maximum allowable concentration of 10 µg/l in drinking water total arsenic (organic and inorganic) [17]. In the past 30 years, bottled water consumption has been rising in many populations [20]. Packaged water is classified into two mineral water and bottled water [21]. Packaged water adds various additives such as trace elements, etc. into water, but in mineral water, bottled water is filled with spring water without additives [22]. Many studies have measured concentrations of heavy metals in bottled water and have evaluated and calculated non-carcinogenic and carcinogenic risks in different age groups [29-23]. Due to the importance of arsenic health risks in drinking water and high use of water, especially bottled water (due to the hot and humid weather) at Bandar Abbas, it has been attempted in this study to calculated and evaluate carcinogenic and non-carcinogenic risk in adult men and women and children.

Materials and Methods

Study area

The coastal city of Bandar Abbas (the capital of Hormozgan Province) is located in southern Iran (N "53'11°27 and E"722°54) at an elevation of 9 meters above sea level (Figure 1) [30]. The city's climate is hot and humid and the population is increasing day by day due to business growth[31].

Sample collection

This cross-sectional study is conducted in the summer and winter of 2013. Samples collection was conducted out of high-consumed eight brands of packaged water in Bandar Abbas from (Figure 1). This 13 locations was selected According to density dwelling and population in the city. In each month, nine 1.5 liter bottles were randomly collected from each brand. 216 water samples in summer and 216 samples in winter (a total of 432 samples of bottled water) were collected (table 1). Samples were transferred to the Chemical laboratory at Hormozgan University of Medical Sciences according to the chemical sampling procedure, at 4-6 C ° for measuring the concentration of heavy metals [32].

Arsenic concentration analysis

In the laboratory, ml 1 nitric acid (65%) per liter of water sample, to reach 2 PH <
(for maintaining heavy metals in water samples up to 28 days) was added to the water samples. To concentrate, water samples were passed through Whatman glass microfiber filter (GF/C) [33]. Measurement arsenic concentration was done by atomic absorption spectrophotometry DR2800 model in Method 8013 silver diethyldithiocarbamate method detection limit (0-200 µg/l)[34] [35].

**Statistical analysis**

The difference of mean arsenic concentration in different brands of bottled water, difference arsenic concentrations in summer and winter, carcinogenic and non-carcinogenic risk difference in different age groups using T test and One Way ANOVA were analyzed by SPSS16 software. Error of five percent (α= 5) was considered as significant level.

**Risk analysis**

Chronic Daily Intake (CDI) was calculated by the calculation presented by United States Environmental Protection Agency [36]:

\[ \text{CDI} = C \times \text{DI} / \text{BW} \]

In this equation, CDI is chronic daily intake (mg/kg-d), C; concentration of contaminants (arsenic) in drinking water (mg/l), DI; average daily water consumption (l/d) and BW and body weight is (kg). DI for adult men (65-17 years), adult women (65-17 years) and children (14.4 years) is 2.723, 2.129 and 1.8 l/d, respectively and BW is 76, 64 and 22.3 kg, respectively .[38 ,37] Carcinogenic risk of heavy metals is caused by eating or drinking can be calculated by Equation 2 [39].

\[ \text{R} = \text{CDI} \times \text{SF} \]

In this equation, R is carcinogenic risk from lifetime exposure to contaminants (As); CDI is chronic daily intake (mg / kg-d) and SF, pollutant slope factor (kg-d/mg) depending on the pollutant concentration or dose). SF for arsenic is 1.5 kg-d / mg. Acceptable levels of R based on EPA and WHO is less than 1E-6 (one cancer per million people) and less than 1E-4 (one cancer per 10,000 people).[41 ,40 ,17]

Hazard Quotient) HQ): to calculated non-carcinogenic risk of arsenic in water, it is calculated by Equation 3:

\[ \text{HQ} = \text{CDI} / \text{RfD} \]

In Equation 3, RfD is pollutants reference dose (mg/kg-d). RfD for arsenic is 0.0003 mg/kg-d [3]. A population is in a safe area when HQ<1 [42].

**Results and Discussion**

Mean (M ± SE) and range arsenic concentrations is 5.67±0.73 µg/l and 0.9-16.3 µg/l. Mean arsenic concentrations of is less than the standard of WHO and EPA (10.1 µg). Mean arsenic concentrations in brands BW1, BW2, BW3, BW4, BW5, BW6, BW7 and BW8 are 6.33±0.93, 5±0.68, 3±0.37, 1.33±0.39, 6±0.76, 7.83±1.23, 11.33±1.39 and 10.5±1.2 µg/l (Table 2). A significant relationship was observed between mean arsenic concentrations of in summer and winter in brands BW2, BW3, BW4 and BW5 (p value < 0.05). This difference could be due to changes in water supply, changes in the type of clean-up and entry of probable pollution in one season. Given the mean arsenic concentrations, the brands of bottled water are BW7>BW8 BW6>BW1>BW5> BW2> BW3>BW4, respectively. The highest and
lowest mean arsenic concentrations relates to BW7 and BW4 (Table 2). Arsenic concentrations for brands BW1, BW2, BW3, BW4, BW5, BW6, BW7 are 3.9-11, 4.9-5.3, 3-3.1, 0.9-5.2, 5-11.3, 4.9-16, 2.8-16.3 and 4.9-15.3 µg/l. According to WHO guidelines and maximum permissible concentrations of EPA (10 µg/l), Mean arsenic concentrations in BW8 and BW7 brands is higher than the standard level.[43,16] In addition, concentration range of brands BW1, BW6, BW8, BW7 and BW5 in some cases is higher than the standard level (Figure 2).

Range arsenic concentrations in the study of Bakirdere et al. (8.51-11.54 µg/l) in our study range (0.9-16.3 µg/l). Mean arsenic concentration in our study (5.67±0.73 µg/l), such as the study conducted by Bakirdere et al. is less than WHO and EPA standard level (10 µg/l).[44] Concentration range of arsenic in bottled water in the study of Ficket et al. (0.143-2.999 µg/l) is in our study range.[6]

Arsenic can be seen in Figure 3, 28.4% (123 samples) of total samples (432 samples) have concentrations greater than the WHO and EPA standards. Chronic daily intake (CDI) for the age groups of adult men, adult women, and children, is 20E-5, 18E-5 and 45E-5 mg/kg-d. The highest and lowest CDI relates to BW7 brands (91E-5) for children and BW4 (4E-5) for adult women (Table 3). CDI order for different age groups is children> male> female adult. CDI for children approximately 2.25 times more than CDI in adult men and women (p value <0.05). CDI in the study of Rajai and his colleagues (9.7E-5 in autumn and spring season’s 4.1E-5 mg/kg-d) is lower than our study (20E-5, adult male) due to lower arsenic concentration.[27] Mean risks of arsenic carcinogenicity (R) for adult men, adult women, and children are 30E-5, 28E-5, 68E-5, respectively (Table 3). The order of carcinogenic risk is children> male> female adult.

| Table.1 The number of sample water in summer and winter seasons 2013 |
|---|---|---|---|---|---|---|
| Locations | Summer | | | winter | | |
| | July | August | September | January | February | March |
| 1 | 6 | 9 | NC | 9 | 6 | 6 |
| 2 | 3 | 3 | 6 | 9 | 3 | 6 |
| 3 | NC | 3 | 6 | 9 | 6 | 6 |
| 4 | 6 | 6 | 6 | 6 | 6 | NC |
| 5 | 9 | 3 | 6 | 3 | 3 | NC |
| 6 | 3 | 6 | 9 | 6 | 6 | 6 |
| 7 | 3 | 6 | 9 | 6 | 6 | 9 |
| 8 | 6 | 6 | 3 | 3 | 6 | 6 |
| 9 | 6 | 6 | 9 | 6 | 6 | 9 |
| 10 | 9 | 6 | 6 | NC | 3 | 6 |
| 11 | 12 | 9 | 6 | NC | 9 | 6 |
| 12 | 3 | 6 | 3 | 6 | 9 | 3 |
| 13 | 12 | 3 | 3 | 9 | 3 | 9 |
| SUM | 72 | 72 | 72 | 72 | 72 | 72 |
| SUM | | 216 | 216 | | | |

1 Not collected
Table 2 Mean, standard deviation and range arsenic concentrations in eight brands of bottled water in Bandar Abbas in summer and winter 2013

<table>
<thead>
<tr>
<th></th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>August</td>
<td>July</td>
</tr>
<tr>
<td>BW1</td>
<td>0.766±0.7</td>
<td>6±0/65</td>
</tr>
<tr>
<td>BW2</td>
<td>ND³</td>
<td>ND</td>
</tr>
<tr>
<td>BW3</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>BW4</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>BW5</td>
<td>2.1±11.0</td>
<td>57.5±0</td>
</tr>
<tr>
<td>BW6</td>
<td>5±0/57</td>
<td>ND</td>
</tr>
<tr>
<td>BW7</td>
<td>21.10±1</td>
<td>48.12±1</td>
</tr>
<tr>
<td>BW8</td>
<td>34.11±1</td>
<td>0.938±</td>
</tr>
</tbody>
</table>

Table 3 CDI, R and H in adult men, adult women, and children caused by arsenic in bottled water in Bandar Abbas

<table>
<thead>
<tr>
<th>C (μg/l)</th>
<th>CDI mg/kg-d</th>
<th>R</th>
<th>HQ</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Children</td>
<td>Adult men</td>
<td>Adult women</td>
</tr>
<tr>
<td>BW1</td>
<td>6.33</td>
<td>–5E51</td>
<td>–5E21</td>
</tr>
<tr>
<td>BW2</td>
<td>5</td>
<td>–5E40</td>
<td>–5E17</td>
</tr>
<tr>
<td>BW3</td>
<td>3</td>
<td>–5E24</td>
<td>–5E41</td>
</tr>
<tr>
<td>BW4</td>
<td>1.33</td>
<td>–5E11</td>
<td>–5E4</td>
</tr>
<tr>
<td>BW5</td>
<td>6</td>
<td>–5E48</td>
<td>–5E20</td>
</tr>
<tr>
<td>BW6</td>
<td>7.83</td>
<td>–5E63</td>
<td>–5E26</td>
</tr>
<tr>
<td>BW7</td>
<td>11.3</td>
<td>–5E91</td>
<td>–5E38</td>
</tr>
<tr>
<td>BW8</td>
<td>10.5</td>
<td>–5E85</td>
<td>–5E35</td>
</tr>
<tr>
<td>MEAN</td>
<td>5.67</td>
<td>–5E45</td>
<td>–5E18</td>
</tr>
</tbody>
</table>

² Standard Deviation
³ Not Detected or zero
Figure.1 Locations of bottled water sample collected at the city of Bandar Abbas in southern Iran

Figure.2 comparing the mean and range arsenic concentrations in bottled water by WHO and EPA standards
Figure 3 Relative percentage frequency distribution of arsenic concentrations in 432 samples of bottled water in Bandar Abbas

Figure 4 Comparison of the carcinogenic risk of adult men, adult women, and children to the acceptable levels of EPA and WHO
Carcinogenic risk among children is approximately 2.26 times more than adult women and men (p value<0.05). Because children have less weight than that of adult men and women (less than 60-40%), hence, CDI, followed by R, is higher than the other groups (weighted inversely with the CDI, Eq. 1) [38]. The highest carcinogenic risk relates to brand BW7 (children, 137E-5) and the lowest one relates to mark BW4 (adult female, 6E-5). Mean carcinogenic risk for all age groups, due to higher water consumption, is higher than acceptable levels of EPA (1E-6) and an acceptable level of WHO (1E-4) (Figure 4).[41,40]

The carcinogenic risk in the study conducted by Wang and colleagues for children (46E-5) and adult (21.4E-5) was less than the one obtained in our study due to lower arsenic concentrations (3.8μg/l). Also, in the study of Wang et.al as our study, carcinogenic risk for children is more than 2 times for [3]. The carcinogenic risk in the study done by Rajaie et.al was 2.32E-4 , which due to lower arsenic concentration (2.28 μg/l in autumn and 0.97 μg/l in spring) was quite lower than our study (30E-5, adult men), (Table 3) [27]. The carcinogenic risk in the study done by Kavcar et.al (adults, 0.000151) was less than that of our study (adult men, 0.0003). Although the mean arsenic concentration in the study by Kavcar (6.47 μg/l was more than our study (5.167 μg/l), due to the consideration of lower water consumption (2 l/d), compared to our study (2.723 l/d), there is also less risk of carcinogenicity [36].

Non-carcinogenic risk for adult men, adult women, and children are 0.67, 0.62 and 1.52, respectively. The order of non-carcinogenic risk is children>male> female adult. Non-carcinogenic risk for children is
2.33 times more than adult men and women (p value<0.05). Mean non-carcinogenic risk in children is more than 1 but less than 1 in adult men and women (Table 3). Non-carcinogenic risk in the study done by Kawcar and colleagues (HQ=0.5, adults) due to lower CDI, is lower than our study (HQ=0.67, male) [36]. Non-carcinogenic risk in the study by Rajaie et.al is 2.53E-4 that is much lower to our study (Fig. 5) [27].

Although the mean arsenic concentration of in bottled water is less than the WHO and EPA standard, carcinogenic risk of arsenic for adult men, adult women, and children is higher than acceptable levels of EPA (1E-6) and WHO (1E-4). Non-carcinogenic risk for adult men and women is less than 1 but greater than 1 for children. Carcinogenic and non-carcinogenic risk for children is 2 times more than adult men and women. All age groups, especially children, are at risk in terms of carcinogenic risk of arsenic bottled water. Also, the non-carcinogenic risk in men and women over age group is in a safe range (1>HQ) but children are unsafe in this limit (1<HQ).

Acknowledgements

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