Health risk assessment of arsenic in drinking groundwater: A case study in a central high land area of Vietnam

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Abstract. Arsenic contaminated groundwaters is a global environmental issue which cause serious problems for human health risks. 188 groundwater samples were collected in private wells of Lam Dong Province, a central highland area, Vietnam to investigate the health risks to the local people by using arsenic contaminated groundwater for drinking purpose. The result showed that the arsenic concentration is average of 14 μg/L and maximum of 500 μg/L. About 12% out of the total groundwater samples have arsenic concentration exceeded that value of 10 μg/L recommended for drinking water by World Health Organization (WHO, 2019). The health risk assessment showed that hazard quotient (HQ) value for adults was up to 60.6 with an average of 1.7 and about 14% of total samples show the HQ values greater than 1. The HQ value for children is average of 4.7 (maximum of 166.7) and about 23% of total groundwater samples show HQ > 1 for children. Cancer risk (CR) values were up to 27x10⁻⁴ (average of 8x10⁻⁴) for adults and 75x10⁻⁴ (average of 21x10⁻⁴) for children. About 26% and 29% of out of the total samples show CR value for adult and children greater than the CR (1x10⁻⁴) proposed by the USEPA. The result also indicated that the consumption of arsenic contaminated groundwater may seriously damage the human health. Therefore, groundwater in the area needs to be treated for arsenic removal before drinking to minimize the adverse effect on local communities’ health.

Keywords: Arsenic, groundwater quality, health risk assessment, Lam Dong province, central high land area

1. Introduction
Arsenic (As) is one of ten chemicals that considered as the major public health concern by the World Health Organization (WHO). As poisoning in sort period of time can cause muscular weakness and muscle cramps, nausea, vomiting, and diarrhea [1]. Long term exposed to arsenic can lead to diseases like cancers, skin lesions, diabetes, hypertension, etc. Arsenic is a potent genotoxic agent for animals and humans that can damage DNA, induces chromosomal aberrations, sister chromatid exchange and micronuclei formations [1]. As is a natural chemical of the Earth’s crust and mobilise to water resources by biogeochemical processes [2,3]. Using arsenic rich groundwater for drinking and domestic use is widely known as the most common reason for long-term exposure.

Worldwide, million people are exposed to arsenic due to using As-contaminated groundwater for daily needs [4]. The current recommended limit of arsenic in drinking-water is 10 µg/L [5]. As rich groundwater (As >10 µg/L) is widely observed in many parts of the world such as Australia [6], Bangladesh [4], China [7], India [8], USA [9], South Korea [10] and Vietnam [11]. Flanagan et al. [4] estimated that about 20 million and 45 million people in Bangladesh were exposed to As concentration greater than 50 µg/L and 10 µg/L respectively and approximately 24,000 deaths annually in the country due to the consumption of As rich groundwater.

Arsenic rich groundwater is also commonly observed in Mekong Delta [11], Red River Delta [12] of Vietnam. Geological condition such as rich organic matter in sediment, low Eh in groundwater is the main cause for As mobilisation in these areas [13]. Consequently, As concentration is up to 1,300 µg/L in groundwater of the Mekong Delta and 3,000 µg/L in groundwater from the Red River Delta [14]. Because groundwater is very important sources for drinking and irrigation purposes, million people in Mekong Delta [15] and Red River Delta could be exposed to As. Berg et al. (2007) observed a significant concentration of As in hair and nails collect from people drinking As rich groundwater in Mekong Delta [15].

High Arsenic concentration up to 800 ug/L was also observed in Lam Dong Province, a central high land area of Vietnam [16,17,18]. Groundwater is also very important for water supply in the area. Several studies have conducted to investigate As concentration in some districts such as Cat Tien [16,17], Da Teh [18] of Lam Dong Province. They found that As rich groundwater is observed even in sedimentary rock aquifers and associate with negative Eh environment. In this study, we will estimate the health risk of resident to As contaminated groundwater. This information will be valuable to water policy makers and planner to find the measures for avoiding health problems of residents.

2. Study area

The study area comprises four Southern districts of Lam Dong province in the central highland region of Vietnam (Figure 1), namely Cat Tien, Da The, Da-Houai, and Bao Loc. The total area is about 9,700 km² and population of 1.6 million people. The elevation varies from 500 to 2,300 m above the mean seawater level. This is a mountainous province with a tropical climate characteristic, in which the rainy season starts from April to November and the dry season lasts from December to March in the following year. Annual rainfall is about 1,600 to 2,700 mm. Temperature varies from 16 to 23°C. Land use is mostly forest (up to 70% of total land) and some scatter of urban, resident, and agricultural areas. Lam Dong has a dense network of rivers and streams with an average density of 0.6 km/km². Total area of rivers and streams is about 9232 ha. Lam Dong also has a reservoir system with a large water reserve serving people's demands for domestic, irrigation, agriculture, and tourism.

Geological characteristic is dominated by basalt and other rocks such as sedimentary rocks and intrusive rocks. The unconsolidated sediment of Neogene and Quaternary was found in small parts in Cat Tien, Da Teh and Bao Loc. Hydrogeology in Lam Dong province is divided into seven types of aquifers, including Holocene sediments (Qh), Neogene sediments (N1-3-N1-4d1), Pleistocene basalt rocks (βQ1), Pliocene – Pleistocene basalt rocks (βN2 – Q1), Pliocene sedimentary rocks (βN2), Creta sedimentary rocks (K2) and Jura sedimentary rocks (J1-2). Groundwater is abstracted from dug well installed in shallow depth (i.e. several meter in depth) and drilled wells installed to deep aquifers (up to 70 m in depth).
3. Methods

3.1. Dataset
This study utilized dataset that includes information of groundwater samples (As concentration, pH) and wells (depth, types, location) and water treatment tools for drinking purpose of 188 groundwater samples collected from private wells. The groundwater samples and related information were collected by Department of Natural Resources and Environment of Lam Dong Province in 2007 from the Southern area, including Cat Tien, Da Huoi, Da Teh, and Bao Loc districts of Lam Dong province. The location of groundwater samples is shown in Figure 1.

3.2. Health risk assessment
The risk assessment for human health of As in groundwater through drinking and domestic purposes for two groups of residents: children and adults.

Dose assessment and exposure assessment:
The average daily dose (ADD) is calculated as equation (1).

\[
ADD = \frac{(C \times IR \times EF \times ED)}{(AT \times BW)}
\]  

Where: ADD is average daily dose from ingestion (mg/kg.day); C is arsenic content in groundwater samples (mg/L); IR is water intake rate, 1 L/day for children and 2 L/day for adults (Nguyen et al., 2020); EF is exposure frequency (365 days/year); ED is exposure duration, 10 years for children and 70 years for adults. AT is the averaging time for carcinogenic exposure, 3,650 days for children and 25,550 days for adults. BW is the body weight that equals 10 kg for children and 55 kg for adults.

The hazard quotient (HQ) is estimated as following equation 2:

\[
HQ = \frac{ADD}{RfD}
\]  

In which HQ is hazard quotient (unitless); RfD is the reference dose (0.0003 mg/kg.day) [19]. HQ is calculated for non-carcinogenic exposure. If HQ is greater than 1, a non-carcinogenic risk is considered to be possible [19]. On the contrary, no health effects are expected.
The carcinogenic risk (CR) is calculated as equation 3:

\[ \text{CR} = \text{CSF} \times \text{ADD} \]  \hspace{2cm} (3)

In which CSF is the cancer slope factor for arsenic (1.5 mg/kg.day) [14]. The highest safe standard for carcinogenic risk is \(10^{-4}\) [19].

4. Results and discussion

4.1. Occurrence of Arsenic rich groundwaters

Generally, arsenic concentration in groundwater samples is up to more than 500 ug/L. About 12% of the total groundwater samples (n=188), As concentration is greater than that values in drinking water guidelines of WHO, 2017 (10 ug/L for As). The high Arsenic concentration is generally observed in Da-Teh district, and some sites in Cat Tien and Da-Huoai districts (Figure 2). About 94% of total investigated wells (n=188) groundwater was pumped for drinking and domestic uses directly without any treatment. Only 7% of the wells’ owners simply filter pumped water by sand treatment before using.

![Figure 2. As concentration in groundwater samples from Bao Loc, Cat Tien, Da Huoai, and Da-Teh districts](image)

The groundwater pH varied from 5 to 8 (Figure 3a). High Arsenic concentration generally observed when pH of groundwater is from 6 to 8. The As concentration in groundwater collected from drilled wells (average of 54 ug/L) are much greater than in dug wells (average of 5 ug/L). Generally, As concentration increases as a function of well depth (Figure 3b). The highest concentration of As is observed in the well depth of 40 and 60 m below land surface. This observation is consistent to the investigation of Nguyen and Nguyen [17] and Nguyen and Truong [18] in Cat Tien and Da Teh districts, respectively. These studies show that the highest As concentration in groundwater samples collected from Cat Tien (400 ug/L) and Da Teh districts (820 ug/L) were observed at the well depth of 30 and 180 m below land surface, respectively. Studies in Da-Teh and Cat Tien show that high As rich groundwater occurred in both unconsolidated sedimentary and sedimentary rocks and associated to negative Eh values, high pH (6-8), iron and NH\(_4\) concentrations. The As concentrations in core samples collected in Da Teh [18] and Cat Tien districts [16] were up to 11.54 mg/kg and 11.58 mg/kg, respectively for unconsolidated sediment and up to 28 mg/kg and 154 mg/kg, respectively for sedimentary rocks.

Kim et al. [10] also observed low As concentration in shallow unconsolidated sediment aquifers and higher As concentration in deeper depth wells installed in bedrock aquifers from agricultural area of
South Korea. Kim et al. [10] also suggested that shallow groundwater is influenced by agricultural activities that induced oxidising environment; therefore, groundwater in shallow groundwater have higher Eh levels than deep aquifers. In oxidising environment, As can be easily absorbed on surface of iron (hydro)oxides minerals that could lower As concentration in shallow groundwater. In deep wells, groundwater is may under reducing environment, this is a favourable condition for As mobilisation. As concentration is high when groundwater Eh is negative Eh and high pH (6-8) were commonly observed in As rich groundwater from many area worldwide such as Mekong Delta [11], Red River Delta [12], Bangladesh [4]. Reducing environment and high pH induce desorption of As from iron (hydr)oxides surface [2, 3].

![Figure 3. As in groundwater as a function of pH (a) and depth (b)](image)

4.2. Human health risk assessment
The extremely high As concentration (up to 500 mg/L) in groundwater from the study area is 50 folds greater than drinking water limit recommended by WHO [5] (for As 10 ug/L). Most of local residents using the groundwater directly without any treatment. This suggested that the As rich groundwater may threat health of people in the area. The average daily dose (ADD), hazard quotient (HQ), and carcinogenic risk (CR) can be used for health risk assessment. The results indicate that the highest and the lowest values of average CR levels were observed in Da Teh (5.1 x 10^{-4} for adults and 14x10^{-4} for children) and in Bao Loc district (1.4x10^{-4} for adults and 3.9 x10^{-4} for children), respectively. The average CR was already greater than the value of CR 1 × 10^{-4} recommended by the US EPA [19]. About 70%, 8.3%, 18.3%, and 42.2% CR for Adults and 70%, 8.3%, 26.7% and 45.8% CR for Children in Bao Loc, Cat Tien, Da Huoai and Da Teh districts were higher than CR of 1 × 10^{-4}, respectively.
Table 1. HQ and CR for Adult and Children from Bao Loc, Cat Tien, Da Huoai and Da Teh districts.

|                | Bao Loc (n=10) | Cat Tien (n=60) | Da Huoai (n=60) | Da Teh (n=59) |
|----------------|----------------|-----------------|-----------------|---------------|
|                | Mean SD (%)    | Mean SD (%)     | Mean SD (%)     | Mean SD (%)   |
| HQ_adults      | 0.32 0.27 0%   | 0.99 4.97 6.7%  | 0.46 1.49 11.7% | 3.92 11.3 27.1% |
| HQ_Child       | 0.87 0.74 40%  | 2.72 13.7 8.3%  | 1.25 4.09 16.7% | 10.79 31.1 42.4% |
| CR_adults (x10⁻⁴) | 1.4 1.2 70%   | 4.4 22.4 8.3%   | 2.1 6.7 18.3%   | 17.7 50.9 42.4%  |
| CR_Children (x10⁻⁴) | 3.9 3.3 70% | 12.3 61.5 8.3%  | 5.6 18.4 26.7%  | 48.5 139.9 45.8% |

Notes: SD is standard deviation; (%) indicates the percentage of total sample exceeding the US EPA standard for CR and HQ [19].

5. Conclusion
Arsenic contamination in groundwater has been considered as an alarming issue in the Southern area of Lam Dong province with the highest contaminated level of 500 µg/L, 50 times higher than the WHO guidelines for arsenic content in drinking water. 11.7% of total (n=188) samples exceeded the drinking water limit for As (10 µg/L). Among four surveyed areas, Da Teh district were much more polluted than other districts. The high level of arsenic would threaten to human health of residents consuming groundwater for drinking and living activities. The health risk assessment showed that 25.5% and 29.3% of the carcinogenic risk values for adults and children exceeded the highest acceptable value of (10⁻⁴) proposed by US EPA. In addition, the average CR value for children was higher than these for adults. These results are warning about the arsenic polluted level in groundwater and the communities’ health problems in the study area. The dataset also indicated that 93% of surveyed wells, the groundwater was pumped directly without any treatment and 7% of wells, pumped groundwater was simply treated by sand filtering. This way of using groundwater is unsafe for human health. Therefore, treatment technologies for arsenic removal should be applied for preventing the arsenic exposure and reducing the risk of diseases and cancer in local residents. Simultaneously, it is necessary to monitor the groundwater quality in the area.

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