Health risk assessment of groundwater consumption for drinking and domestic purposes in Xuyen Moc District, Ba Ria – Vung Tau Province, Vietnam

A H Nguyen1,3*, M P L Nguyen1,3, N T T Pham1, V M H Tat1,3, L K Luu1,3 and P L Vo2,3*

1 Department of Geospatial Information System and Remote Sensing, The Institute for Environment and Resources, 142 To Hien Thanh Street, District 10, Ho Chi Minh City, Vietnam
2 Faculty of Environment & Natural Resources, Ho Chi Minh City University of Technology (HCMUT), 268 Ly Thuong Kiet Street, District 10, Ho Chi Minh City, Vietnam
3 Vietnam National University Ho Chi Minh City, Linh Trung Ward, Thu Duc District, Ho Chi Minh City, Vietnam

*Corresponding authors: haiauvtn@gmail.com; and volephu@hcmut.edu.vn

Abstract. Groundwater in Xuyen Moc district is currently exploited for many purposes such as irrigation, domestic, production and livestock activities. In this study, the health risk assessment (HRA) method was used to determine the risks of public health for local people consuming groundwater for their domestic purposes by using the hazard quotient (HQ). This method calculated HQ of parameters exceeding the allowable limit in drinking water through monitoring data and the survey of households in the study area. Fourteen (14) groundwater samples were collected in the dry and wet seasons in 2017. Eleven (11) water quality parameters (pH, total hardness, TDS, SO\textsubscript{4}\textsuperscript{2-}, Cl\textsuperscript{-}, NO\textsubscript{3}\textsuperscript{-}, F\textsuperscript{-}, Mn\textsuperscript{2+}, Fe\textsuperscript{2+}, Zn\textsuperscript{2+} and Pb) were selected for analysis. Results of calculation of HQ showed that fluoride is a parameter affecting the health of children when using groundwater for a long-term (HQ > 1). HQ values ranged from 1.9 to 2.2 through ingestion of water and HQ through the dermal absorption ranged from 4.710^{-4} to 8.610^{-4}.

1. Introduction

Xuyen Moc District is located in a region with disadvantages of groundwater extraction. The reasons for the limitations of water extraction include (1) the average flow of low wells is 10 - 15 m\textsuperscript{3}/h, so on average one km\textsuperscript{2} can only extract 1.437 m\textsuperscript{3}/day and (2) a low level of homogeneity [1]. Although, Xuyen Moc district is disadvantage region to extract groundwater, but people in the area still have a habit of using groundwater as the main water source, in addition the water supply is not enough to meet demand for residents in the dry season. Therefore, in order for residents to use water easily, especially for shallow aquifers (Holocene, Pleistocene and Pliocene), it is necessary to evaluate the groundwater quality and health risk when using the source water for domestic. In Xuyen Moc District, besides tapping water, groundwater is used for drinking and domestic purposes [1].

Heavy metals occurring in groundwater are originated from natural ores, the intrusion of waste from industrial or craft enterprises [2]. Iron is usually present in groundwater because iron-containing minerals such as piroxene, amphibon, magnetite, pyrite, biotite, etc. are weathered into weak and stable
dissolved iron oxides in the form of protoxides (Fe$^{2+}$) and oxide (Fe$^{3+}$). Iron protoxide compounds are unstable when exposed to oxygen or oxidizing agents to form iron hydroxides in the form of colloids that exist in water [3]. When iron concentration in groundwater is more than 0.5 mg/l, the water smells fishy and floating appear on the surface. Using iron-containing water will lead to damages in products and clothes. Besides Iron, Manganese appears in groundwater with concentration less than 2 mg/l. However, when the Manganese concentration exceeds the permitted limit, it will affect to human's health [4]. Manganese concentration in water below 0.05 mg/l will not affect human activity [4], however concentrations between 0.1 and 0.15 can cause problems with taste and stains [5, 6]. Manganese in the human body, which maintains important enzymes and enhances the bone formation process, is required for protein synthesis as well as lowers blood sugar; however, if the level of Manganese exceeds the permitted level, it will lead to poisoning phenomenon, causing neurological disorders with manifestations of Parkinson's disease [7]. Lead occurs in soil and groundwater is originated from minerals and parent rock. Lead contained in sandy soils in nature does not exceed 16 mg/kg. The solubility of lead-containing minerals is low in the environment, lead is less variable than other elements such as Zinc and Cadmium. In addition to natural sources, lead presents in soil and groundwater due to infiltrate of industrial wastewater and agricultural activities such as fertilization, lime fertilization and pesticides using [8]. Long-term use of water with high lead concentration can causes risks to human health such as mental disorder, headache, seizures, epilepsy or death [9].

Along with heavy metals, fluorine compounds infiltrate in groundwater through soil pollution [10]. The concentration of fluoride in water depends on many factors such as pH, total solids, alkalinity and hardness [11, 12, 13, 14]. Small amounts of fluoride are needed for bone formation, tooth enamel and tooth decay. On the other hand, too much fluoride can cause damage to human bones and teeth [15, 16, 17, 18, 19, 20]. Fluoride may have the structural, functional and metabolic effects on soft tissues such as the kidneys, liver, lungs and testicles [21, 22, 23, 24] and may decrease the IQ$^1$ in children. High fluoride concentration has a neurotoxic effect as well as the potential of causing bone cancer [25, 26].

Although, based on geological surveys, the aquifers in Xuyen Moc district are characterized by sediments originated from rivers, ocean and wind. The results of mineral composition analysis showed mainly sand, rock crystal, clay, rock and no minerals containing lead and fluoride [1].

Health risk assessment (HRA) appeared in the 1980s. This is a method of assessing the relationship between environmental pollution and human health, expressed through the quantitative description of pollution risk with human health [27]. The health risk assessment method has been recommended by the United States Environmental Protection Agency (USEPA) and widely used in the world such as China [28], Cambodia [29], Jordan [30], Pakistan [31] and many countries in the world. These studies have applied the HRA method to assess the health risks of people using groundwater based on the hazard index (HI - Hazardous Index) to perform recommendations, zoning, monitoring and management water source. The health risk assessment (HRA) method has also been applied to assess the health risks of residents to arsenic (As) pollution in Ho Chi Minh City, specifically at 15 water monitoring points groundwater in Ho Chi Minh City. The results showed that groundwater throughout the city has a low health risk [32]. In addition, another study was carried out in the suburbs of Ho Chi Minh City to evaluate the health risks to people exposed of radioactive elements Uranium (U) and Thorii (Th) in groundwater, specifically in the three aquifers of the Pleistocene (lower Pleistocene (qp1), Middle-upper Pleistocene (qp2.3) and Upper Pleistocene (qp3), results of calculating hazard quotient (HQ) showed no risk of negative effects on health (HQ < 1) [33]. The above studies proved that using this method is a suitable to assess the health risks of groundwater for drinking and domestic purposes. Nowadays, there is no study on health risk assessment for heavy metals and fluoride in Xuyen Moc district so that this study is to assess the health risks of residents in Xuyen Moc district, Ba Ria - Vung Tau province.

$^1$IQ (Intelligent quotient): IQ scores are often linked to academic, work and social success, with recent studies showing a correlation between IQ and health, longevity (smart people), there is often more knowledge in self-care) and also the number of words the person uses. (National Council on Measurement in Education 2016 Glossary of important assessment and measurement terms pp 36-41)
2. Materials and method

2.1. Study area
Xuyen Moc district has 05 aquifers including Holocene aquifers (qh) (VT20) with the depth below 3-25 m; Pleistocene aquifers (qp2) (including borehole VT19, VT23), with a depth of 0 - 44 m; Pliocene aquifers (n2) (including borehole VT22, VT24B, VT25B), with a depth of 0 - 30 m; Pliocene - Pleistocene (Bn2-qp2) (including borehole VT24C, VT35), has a depth of 0 - 50 m and Jura aquifers (j2) belong to the group of basalt rocks. In which, the four aquifers of Holocene (qh), Pleistocene (qp2), Pliocene (n2) and Pliocene - Pleistocene (Bn2-qp2) have a wide distribution area and large storage volume. The proportion of borehole is unevenly distributed, 21.4% of borehole are concentrated in Bau Lam and Hoa Hiep communes, 14.3% of borehole are distributed in Binh Chau, Tan Lam, Phuoc Tan communes and the rest of the borehole concentrated in Hoa Hoi commune. The main petrographic composition of the Holocene aquifer is mainly sand and sand mixed with clay. Pleistocene (qp2) is a fine-grained sand to a coarse gravel, where silty clay is mixed thin lenses of silty clay, fine sand powder. Pliocene aquifer (n2) is sand mixed with white crystal gravel, sometimes mixed with clay, often sandwiched by layers or thin lenses of clay, silty clay and Pliocene - Pleistocene (Bn2-qp2) are fractured basaltic eruptions of the Tuc Trung formation [1].

2.2. Materials and method

2.2.1. Materials
In this paper, eleven quality parameters (pH, Hardness, TDS, SO\textsubscript{4}^{2-}, Cl\textsuperscript{-}, F\textsuperscript{-}, Fe\textsuperscript{2+}, Mn\textsuperscript{2+}, Zn\textsuperscript{2+}, Pb) from fourteen monitoring borehole (VT20, VT19, VT23, VT22, VT24A, VT24B, VT24C, VT35, VT18, VT21, VT25A, VT25B, VT36, VT38) in Xuyen Moc district is treated and assessed in the dry and wet seasons. The locations of the borehole are presented in Figure 1.

![Figure 1](https://example.com/figure1.png)

**Figure 1.** Map of Xuyen Moc district showing borehole sites. [1]

2.2.2. Human health risk assessment
All mathematical and statistical calculations are performed using EXCEL 2016 software (Microsoft Office).
Defined by the United States Environmental Protection Agency (US EPA), human health risk assessment is the process to estimate the nature and probability of adverse health effects in humans who may be exposed to chemicals in contaminated environmental and conducted base on 04 steps [34]:

**Step 1: Hazard Indentification**

Contaminants are considered to cause effects on human health whether determining toxicity characteristics. In this part, eleven parameters are divided into 02 groups: carcinogenic pollutant factors and non-carcinogenic factors include: Fluoride (F\(^-\)), Nitrate (NO\(_3^-\)), Iron (Fe), Chloride (Cl\(^-\)) and Lead (Pb).

**Step 2: Dose – Respond Assessment**

In this step, the specific relationship between the exposure dose of contaminants and the effects of these parameters is determined through the reference dose (RfD). The values of reference dosage (RfD) used in this study is based on documents of the United States Environmental Protection Agency (USEPA) [35].

**Step 3: Exposure Assessment**

The process of quantitative or qualitative estimation of exposure factors, including exposure pathways, body parameters, exposure frequency, duration of exposure, etc [36]. In this study, the evaluation exposure groundwater through ingestion and dermal absorption. However, there are no studies on risks and environmental toxicity so the parameters to determine the appropriate Exp for residents in Xuyen Moc have not been published. Therefore, this research surveys households to assess exposure frequency, body weight, ingestion rate, exposure duration, exposure time for residents in Xuyen Moc district so that this research surveyed 400 households in 07 communes, as follows: Bau Lam (57); Binh Chau (58); Hoa Hiep (56); Bung Rieng (55); Hoa Hoi (59); Phuoc Tan (57); Tan Lam (58).

Exposure dose for determining human health risk through two pathways have been described in the literature and can be calculated using Eqs.1 and 2 as adapted from the US EPA.

\[
\text{Exp}_{\text{ing}} = \frac{C_{\text{water}} \times \text{IR} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \quad (1)
\]

\[
\text{Exp}_{\text{derm}} = \frac{C_{\text{water}} \times \text{SA} \times \text{KP} \times \text{ET} \times \text{EF} \times \text{ED} \times \text{CF}}{\text{BW} \times \text{AT}} \quad (2)
\]

where: \(\text{Exp}_{\text{ing}}\): exposure dose through ingestion of water (mg/kg/day); \(\text{Exp}_{\text{derm}}\): exposure dose through dermal absorption (mg/kg/day); \(C_{\text{water}}\): average concentration of estimated parameter in water (mg/L); IR: ingestion rate in this study (L/day); EF: exposure frequency (days/year); ED: exposure duration (years); BW: average body weight (kg); AT: averaging time (days); SA: exposed skin area (cm\(^2\)) [18]; KP: dermal permeability coefficient in water, (0.001 cm/h for Mn, Fe, F and 0.004 cm/h for Pb) [19]; ET: exposure time (h/day) and CF: unit conversion factor (0.001 L/cm\(^3\)) [39, 40].

**Step 4: Risk Characterization**

A quantitative description of the magnitude and uncertainty of risk was conducted by integrating the data obtained from previous steps. Potential non-carcinogenic risks due to exposure of parameters were determined by comparing the calculated contaminant exposures from each exposure pathway (ingestion and dermal) with the reference dose (RfD) using Eq.3

\[
\text{HQ}_{\text{ing/derm}} = \frac{\text{Exp}_{\text{ing/derm}}}{\text{RfD}_{\text{ing/derm}}} \quad (3)
\]

where: RfD is ingestion/dermal toxicity reference dose (mg/kg/day).

| Table 1. Hazard quotient (HQ). |
|-----------------------------|
| HQ                          | Risk                  |
| < 1\(^a\)                  | The risk is acceptable |
≥ 1<sup>a</sup> The risk is not acceptable

<sup>a</sup>EPA Drinking water standards and health advisories 2009

According to Integrated risk information system (IRISK) of the United Stated Environmental Protection Agency, the values of RfD are determined in Table 2.
Table 2. The RfD of non-carcinogenic factors.

| Non-carcinogenic | Pb      | Fe   | F     |
|------------------|---------|------|-------|
| RfD_{ing} (mg/kg/day) | 0.0014a | 0.3a | 0.06a |
| RfD_{derm}(mg/kg/day) | 0.00042a | 0.14a | 1a    |

* EPA 2012 Support of Summary Information on the IRIS

3. Results and discussion

3.1. Concentration of parameter in groundwater

All observed parameters in the dry and wet seasons in the study area are determined values by Minimum (Min), Maximum (Max), Mean (Mean) and Standard Deviations (SD) of the data which is presented in Table 3. The results show that concentrations of Lead (Pb), Iron (Fe) and Fluoride (F) parameters exceed the maximum allowable limits in drinking water according to national technical regulation on drinking water quality in Viet Nam (QCVN 01:2009/BYT).

Table 3. Mean, maximum and minimum value of physico-chemical parameters and metals in groundwater from fourteen boreholes in two seasons.

| Parameters and heavy metal | Unit | Dry season | | Wet season | |
|---------------------------|------|------------|---|------------|---|
|                           |      | Max        | Min | Mean | SD | Max | Min | Mean | SD |
| pH                        | -    | 8.0        | 6.3 | 7.2  | 0.6 | 7.6 | 5.7 | 6.6  | 0.6 |
| Hardness                  | mg/L | 226        | 21  | 113  | 73  | 213 | 20  | 84   | 61 |
| TDS                       | mg/L | 306        | 0   | 154  | 90  | 236 | 20  | 109  | 69 |
| SO_{4}^{2-}               | mg/L | 59         | 9   | 27   | 18  | 16  | 0   | 6    | 4  |
| Cl^{-}                    | mg/L | 74         | 0   | 26   | 23  | 38  | 0   | 6    | 9  |
| NO_{3}^{-}                | mg/L | 3          | 0   | 1    | 1   | 6   | 0   | 1    | 2  |
| F                         | mg/L | 16.8       | 0   | 2.3  | 5.0  | 12.0 | 0.3 | 1.7  | 3.1 |
| Pb                        | mg/L | 0.00       | 0.00| 0.00 | 0.00| 0.05| 0.00| 0.01 | 0.01|
| Zn                        | mg/L | 0          | 0   | 0    | 0   | 2   | 0   | 0    | 0  |
| Mn                        | mg/L | 0.6        | 0   | 0.1  | 0.1 | 0.3 | 0.0 | 0.0  | 0.1 |
| Fe                        | mg/L | 4.5        | 0.2 | 1.7  | 1.5 | 19.0| 0.0 | 3.0  | 4.8 |

3.1.1. Dry season (November – March)

In the dry season, monitoring results show that value parameters are within allowable limits. However, according to the limits of parameters in drinking water (QCVN 01:2009/BYT), the pH value observed in some boreholes in the Pleistocene aquifer (q_{p,2}), Pliocene aquifer (n_{2}) and Jura aquifer (j_{2}) was below the allowed drinking water quality limit of the Ministry of Health. In addition, the monitoring results of fluoride concentration in 02 boreholes (VT25B and VT24C) have unusually high values. In addition, the values of iron concentration in all boreholes exceed the permissible limits for water quality used for drinking.

3.1.2. Wet season (April – October)

In the wet season, the results of monitoring parameters are within the permissible limits. The results of pH monitoring at boreholes are within the permissible limits, except for boreholes VT20, VT24C and VT24A, which are lower than the limits of national technical regulation on drinking water quality. The fluoride concentration in the lower Pliocene - Pleistocene aquifer is higher than the permissible limit for
drinking water quality. The concentration of Lead in Pliocene aquifer (VT24B, VT25B) and Jura aquifer (VT36) and iron concentration in all wells are higher than the permissible limit.

3.2. Human health risk assessment

Through surveys and interviews with local people by survey questionnaires in the region of Xuyen Moc District (Ba Ria - Vung Tau province), the boreholes water used with a depth of 3 - 50m is the depth of the Holocene, Pleistocene aquifers, Pliocene aquifers, Pliocene – Pleistocene aquifers. The main purpose of using water of the residents is domestic purposes (72%). In addition, residents use this water source for eating, drinking 32% and bathing at 82%. Besides domestic use, groundwater is used for cultivation and animal husbandry at a rate of 92%. According to the US EPA, three groups of age based on exposure include children under 3 years old, adults under 30 years and the elderly over 65 years. The age of the residents is divided into 04 groups, including: 5 - 16 years, 16 - 40 years, 41 - 60 years and over 60 years. However, Vietnam has not had risk studies in the study area for using water and average age of residents. The study designed the survey questionnaire with the contents focusing on 03 main contents including: the state of the people, the actual state extraction groundwater and the state using of well in the region. The results of the survey and the data monitoring of the parameters will be the input data to assess the health risk for residents in Xuyen Moc district. In order to assess the health risk in the district, this study statistically surveyed two target groups: children (5-16 years old) and adults (16-40 years old, 41-60 years old and over 60 years old). The statistical results show that the average age of children is from 9.5 to 11.5 years old and the adult age is from 43.5 to 46 years old. The average body weight of a child is from 28 to 34.2 kg and the adult is from 50.4 to 62.2 kg.

Table 4. Actual survey results.

|                   | Children | Adults |
|-------------------|----------|--------|
|                   | Boy      | Girl   | Men | Women |
| Number of questionnaires | 44       | 40     | 128 | 188   |
| Average age (years)    | 9.5      | 11.5   | 46.0 | 43.5  |
| Body weight (kg)          | 28.0     | 34.2   | 62.2 | 50.4  |

The results of calculating \( \text{Exp}_{\text{ing/derm}}, \text{HQ}_{\text{ing/derm}} \) for the two seasons dry and wet are presented in Table 6, Table 7, Table 8 and Table 9.

Table 5. Results of calculating \( \text{Exp} \) in dry season.

|                   | \( \text{Exp}_{\text{ing}} - \text{mg/kg.day} \) | \( \text{Exp}_{\text{derm}} - \text{mg/kg.day} \) |
|-------------------|-----------------------------------------------|-----------------------------------------------|
|                   | \( \text{Pb} \) | \( \text{F} \) | \( \text{Pb} \) | \( \text{F} \) |
| Children          |                |                |                |                |
| Boy               | 0              | 1.310^{-1}     | 0              | 8.610^{-4}     |
| Girl              | 0              | 1.210^{-1}     | 0              | 7.710^{-4}     |
| Adults            |                |                |                |                |
| Men               | 0              | 4.510^{-2}     | 0              | 4.710^{-4}     |
| Women             | 0              | 5.410^{-2}     | 0              | 5.610^{-4}     |

In the dry season, the dose exposure in the target groups ranged from 5.410^{-2} to 1.310^{-1} mg/kg/day. Children have greater exposure values than adults through ingestion and skin. The study assessed no lead exposure in the dry season.

Table 6. Results of calculating \( \text{HQ} \) in dry season.

|                   | \( \text{HQ}_{\text{ing}} \) | \( \text{HQ}_{\text{derm}} \) |
|-------------------|-----------------------------|-----------------------------|
|                   | \( \text{Pb} \) | \( \text{F} \) | \( \text{Pb} \) | \( \text{F} \) |
| Children          |                |                |                |                |
| Boy               | 0              | 2.2            | 0              | 8.610^{-4}     |
| Girl              | 0              | 1.9            | 0              | 7.710^{-4}     |
Results of calculating HQ of Lead is smaller than 1 and Fluoride is larger than 1 for children. Fluoride concentration in some boreholes is too high, so when calculating HQ through the drinking ingestion range from $4.7 \times 10^{-4}$ to $8.6 \times 10^{-4}$. From the above results, children have a high health risk associated with using groundwater. The long-term use of fluoridated water suffers from dental and neurological diseases. Therefore, the study put forward to monitor regularly and warn residents in the dry season.

Table 7. Results of calculating Exp in wet season.

|       | Exp_{ing} - mg/kg.day | Exp_{derm} - mg/kg.day |
|-------|-----------------------|------------------------|
|       | Pb        | F        | Pb        | F        |
| Children |          |          |          |          |
| Boy     | 6.7 $\times 10^{-4}$ | 9.6 $\times 10^{-2}$ | 1.8 $\times 10^{-3}$ | 6.3 $\times 10^{-4}$ |
| Girl    | 6.0 $\times 10^{-4}$ | 8.6 $\times 10^{-2}$ | 1.6 $\times 10^{-3}$ | 5.7 $\times 10^{-4}$ |
| Men     | 2.3 $\times 10^{-4}$ | 3.3 $\times 10^{-2}$ | 9.7 $\times 10^{-6}$ | 3.5 $\times 10^{-4}$ |
| Adults  |          |          |          |          |
| Women   | 2.8 $\times 10^{-4}$ | 4.0 $\times 10^{-2}$ | 1.2 $\times 10^{-3}$ | 4.1 $\times 10^{-4}$ |

In the wet season, the fluoride concentration decreases, and the lead concentration increases so the residents have lead exposure when using water. Results of assessing Exp of the age groups in the wet season showed that the level of Exp through drinking was higher than the level of exposure to the skin. In particular, the level of fluoride exposure in children was the highest, ranging from $9.6 \times 10^{-2}$ to $8.6 \times 10^{-2}$ mg/kg/day of oral exposure and $6.3 \times 10^{-4}$ to $5.7 \times 10^{-4}$ mg/kg/day by skin. For adult’s exposure to fluoride is the highest during the wet season when exposure values are between $3.3 \times 10^{-2}$ and $4.0 \times 10^{-2}$ mg/kg/day of oral exposure and $3.5 \times 10^{-4}$ and $4.1 \times 10^{-4}$ mg/kg/day in skin.

Table 8. Results of calculating HQ in wet season.

|       | HQ_{ing} | HQ_{derm} |
|-------|----------|-----------|
|       | Pb        | F        | Pb        | F        |
| Children |          |          |          |          |
| Boy     | 4.8 $\times 10^{-1}$ | 1.6 | 4.2 $\times 10^{-2}$ | 6.3 $\times 10^{-4}$ |
| Girl    | 4.3 $\times 10^{-1}$ | 1.4 | 3.8 $\times 10^{-2}$ | 5.7 $\times 10^{-4}$ |
| Men     | 1.7 $\times 10^{-1}$ | 5.5 $\times 10^{-1}$ | 2.3 $\times 10^{-2}$ | 3.5 $\times 10^{-4}$ |
| Adults  |          |          |          |          |
| Women   | 2.0 $\times 10^{-1}$ | 6.6 $\times 10^{-1}$ | 2.8 $\times 10^{-2}$ | 4.1 $\times 10^{-4}$ |

In the wet season, health risk assessment results of groups showed that health risks still occurred in children when the hazard index ranged from 1.4 to 1.6 (HQ > 1) when children are likely to be exposed to water with a higher concentration of fluoride than the reference dose (RfD). The results also showed that the hazard index of parameters of water use for ingestion purposes was higher than that of skin. In addition, lead is the parameter with the highest hazard index for all groups of subjects when using well water for drinking or skin contact except for children.

4. Conclusion

In this research, health risk assessment method using HQ is applied to evaluate the relationship between human health and pollution in groundwater. Furthermore, this study findings help managers explicitly understand the hazards of health of the residents when using groundwater, thereby giving solutions to limit extraction groundwater and to improve health of residents. For the HQ results, groundwater in Xuyen Moc district is unsafe for drinking and eating purposes, which is a high risk for public health especially children. The research results have increased the concentrations of fluoride, lead and iron in some regions which can be affected by petrographic or human. Therefore, further studies are needed to be carried out in near future to accurately assess public health risks in the area.
Date Availability
The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of interest
The authors declare that they have no conflicts of interest.

Appendices

Table 9. Analysis results of water quality at 14 boreholes in the dry season 2017.

| Parameters | pH  | Hardness | TDS  | SO\textsubscript{4}\textsuperscript{2-} | Cl\textsuperscript{-} | NO\textsubscript{3}\textsuperscript{-} | F\textsuperscript{-} | Zn\textsuperscript{2+} | Pb | Mn\textsuperscript{2+} | Fe\textsuperscript{2+} |
|------------|-----|----------|------|---------------------------------|----------------|----------------|----------------|----------------|---|----------------|----------------|
| VT20       | 6.4 | 51       | 154  | 59                             | 41             | 1              | 0.18          | 0.00          | 0  | 0.1           | 4.0            |
| VT19       | 6.9 | 126      | 171  | 52                             | 14             | 3              | 1.14          | 0.00          | 0  | 0.1           | 0.9            |
| VT23       | 7.2 | 26       | 76   | 38                             | 11             | 0              | 0.0           | 0.00          | 0  | 0.1           | 0.9            |
| VT22       | 7.5 | 121      | 198  | 44                             | 11             | 0              | 0.2           | 0.00          | 0  | 0.1           | 0.9            |
| VT24B      | 7.9 | 21       | 66   | 42                             | 14             | 0              | 0.5           | 0.00          | 0  | 0.0           | 1.1            |
| VT25B      | 7.0 | 69       | 134  | 49                             | 11             | 0              | 0.1           | 0.00          | 0  | 0.1           | 2.7            |
| VT24C      | 6.3 | 31       | 60   | 11                             | 0              | 1              | 12.0          | 0.00          | 0  | 0.1           | 4.4            |
| VT35       | 7.0 | 221      | 0    | 11                             | 0              | 0              | 16.8          | 0.00          | 0  | 0.1           | 2.0            |
| VT18       | 7.6 | 102      | 164  | 15                             | 43             | 0              | 0.3           | 0.00          | 0  | 0.3           | 4.5            |
| VT21       | 7.3 | 191      | 257  | 14                             | 24             | 0              | 0.0           | 0.00          | 0  | 0.6           | 0.4            |
| VT24A      | 7.8 | 191      | 229  | 11                             | 74             | 0              | 0.6           | 0.00          | 0  | 0.1           | 0.4            |
| VT25A      | 8.0 | 173      | 283  | 9                              | 66             | 0              | 0.1           | 0.00          | 0  | 0.0           | 1.0            |
| VT36       | 7.9 | 226      | 306  | 11                             | 11             | 1              | 0.0           | 0.00          | 0  | 0.1           | 0.2            |
| VT38       | 6.3 | 32       | 59   | 9                              | 49             | 1              | 0.0           | 0.00          | 0  | 0.1           | 0.4            |
Table 10. Analysis results of water quality at 14 boreholes in the wet season 2017.

| Parameters | pH   | Hardness | TDS  | SO\(_4^{2-}\) | Cl\(^-\) | NO\(_3^-\) | F    | Zn\(^2+\) | Pb   | Mn\(^2+\) | Fe\(^2+\) |
|------------|------|----------|------|-------------|-------|-----------|------|-----------|------|----------|-----------|
| VT20       | 6.0  | 40       | 114  | 16          | 3     | 0.3       | 0.01 | 0         | 0.0  | 0.3      |
| VT19       | 7.3  | 92       | 133  | 0           | 13    | 3         | 0.6  | 0.03      | 0    | 0.0      |
| VT23       | 6.0  | 21       | 40   | 3           | 7     | 0         | 0.7  | 0.00      | 0    | 0.0      |
| VT22       | 6.4  | 64       | 121  | 4           | 6     | 0         | 0.4  | 0.01      | 0    | 0.0      |
| VT24B      | 7.6  | 38       | 58   | 5           | 2     | 0         | 0.5  | 0.01      | 2    | 0.0      |
| VT25B      | 5.7  | 55       | 100  | 5           | 5     | 0         | 0.5  | 0.00      | 0    | 0.0      |
| VT24C      | 6.4  | 20       | 27   | 7           | 0     | 0         | 4.8  | 0.01      | 0    | 0.0      |
| VT35       | 6.5  | 42       | 20   | 3           | 0     | 0         | 12.0 | 0.01      | 0    | 0.0      |
| VT18       | 6.7  | 93       | 135  | 5           | 5     | 0         | 0.7  | 0.00      | 0    | 0.3      |
| VT21       | 6.4  | 167      | 188  | 11          | 0     | 0         | 0.5  | 0.00      | 0    | 0.2      |
| VT24A      | 6.8  | 167      | 69   | 3           | 5     | 1         | 0.5  | 0.02      | 0    | 0.0      |
| VT25A      | 6.9  | 138      | 232  | 4           | 3     | 0         | 0.8  | 0.00      | 0    | 0.0      |
| VT36       | 7.5  | 213      | 236  | 7           | 3     | 1         | 0.6  | 0.05      | 0    | 0.0      |
| VT38       | 6.0  | 22       | 52   | 8           | 3     | 6         | 0.7  | 0.01      | 0    | 0.0      |

References

[1] People's Committee of Xuyen Moc District 2017 Synthesized report on overall project for environmental protection of Xuyen Moc District to 2020 and orientation to 2030

[2] Lam M T 2015 Environmental engineering Ho Chi Minh City National University Publishing House

[3] Nguyen U and Trinh M T 2012 Handbook of geology and hydrology Construction Publishing House

[4] Water Research Commission 1998 Quality of domestic water supplies Assessment guide

[5] Water S and World Health Organization 2006 Guidelines for drinking-water quality [electronic resource]: incorporating first addendum

[6] DWAF 1996 South African Water Quality Guidelines: Domestic Uses

[7] Hoang T C 2015 Determination and assessment of iron and manganese content in domestic groundwater samples in a few households in Loc Ninh commune - Dong Hoi - Quang Binh, Quang Binh University

[8] Dang T K 2017 Determining lead in soil by extraction-photometric in Cao Lanh city, Dong Thap province Scientific Journal of Tra Vinh University, 1 (25) 56-59

[9] Le H B 2006 Basic environmental toxicity Ho Chi Minh City National University Publishing House 11 pp. 525 - 572

[10] Farooqi A, Masuda H and Firdous N 2007 Toxic fluoride and arsenic contaminated groundwater in the Lahore and Kasur districts, Punjab, Pakistan and possible contaminant sources Environmental Pollution 145 (3) 839-849

[11] Subba Rao N, Prakasa Rao J, Nagamalleswara Rao B, Niranjan Babu P, Madusudhana Reddy P and Devadas D J 1998 A preliminary report on fluoride content in groundwaters of Guntur area, Andhra Pradesh, India Current science 75 (9) 887-888

[12] Rostamia I, Mahvib A H, Dehghanib M H, Baghania A N and Marandid R 2017 Application of nano aluminum oxide and multi-walled carbon nanotube in fluoride removal Desalination and Water Treatment 72 368-373

[13] Dehghani M H, Faraji M, Mohammadi A and Kamani H 2017 Optimization of fluoride adsorption
onto natural and modified pumice using response surface methodology: isotherm, kinetic and thermodynamic studies

Korean Journal of Chemical Engineering 34 (2) 454-462

Rostamia I, Mahvib A H, Dehghanib M H, Baghania A N, Marandid R, 2017 Application of nano aluminum oxide and multi-walled carbon nanotube in fluoride removal Desalination and Water Treatment 72 368-373

Petersen P E 2004 Challenges to improvement of oral health in the 21st century—the approach of the WHO Global Oral Health Programme International dental journal 54 (S6) 329-343

Jones S, Burt B A, Petersen P E and Lennon M A 2005 The effective use of fluorides in public health Bulletin of the World Health Organization 83 670-676

Paudyal H, Pangeni B, Ghimire K N, Inoue K, Ohto K, Kawakita H and Alam S 2012 Adsorption behavior of orange waste gel for some rare earth ions and its application to the removal of fluoride from water Chemical Engineering Journal 195 289-296

Cai H, Xu L, Chen G, Peng C, Ke F, Liu Z and Wan X 2016 Removal of fluoride from drinking water using modified ultrafine tea powder processed using a ball-mill Applied Surface Science 375 74-84

Podgorny P C and McLaren L 2015 Public perceptions and scientific evidence for perceived harms/risks of community water fluoridation: an examination of online comments pertaining to fluoridation cessation in Calgary in 2011 Canadian Journal of Public Health 106 (6) e413-e425

Khorsandi H, Mohammadi A, Karimzadeh S and Khorsandi J 2016 Evaluation of corrosion and scaling potential in rural water distribution network of Urmia, Iran Desalination and Water Treatment 57 (23) 10585-10592

Barbier O, Arreola-Mendoza L and Del Razo L M 2010 Molecular mechanisms of fluoride toxicity Chemico-biological Interactions 188 (2) 319-333

Yang K, & Liang X 2011 Fluoride in drinking water: effect on liver and kidney function, 769-775

Zhang S, Niu Q, Gao H, Ma R, Lei R, Zhang C, ..., and Chen J 2016 Excessive apoptosis and defective autophagy contribute to developmental testicular toxicity induced by fluoride Environmental Pollution 212 97-104

Tang Q Q, Du J, Ma H H, Jiang S J, & Zhou X J 2008 Fluoride and children’s intelligence: a meta-analysis Biological Trace Element Research 126 (1-3) 115-120

Bassin E B, Wypij D, Davis R B and Mittleman M A 2006 Age-specific fluoride exposure in drinking water and osteosarcoma (United States) Cancer Causes & Control, 17 (4) 421-428

Choi A L, Sun G, Zhang Y and Grandjean P 2012 Developmental fluoride neurotoxicity: a systematic review and meta-analysis Environmental Health Perspectives 120 (10) 1362-1368

Han Xiaogang 2011 Urban water quality risk assessment and emergency treatment methods Xi’an University of Architecture and Technology

Zhang Y, Ma R and Li Z 2014 Human health risk assessment of groundwater in Hetao Plain (Inner Mongolia Autonomous Region, China) Environmental Monitoring and Assessment 186 (8) 4669-4684

Phan K, Sthiannopkao S, Kim K W, Wong M H, Sao V, Hashim J H and Aljunid S M 2010 Health risk assessment of inorganic arsenic intake of Cambodia residents through groundwater drinking pathway Water Research 44 (19) 5777-5788

Batayneh A T 2012 Toxic (aluminum, beryllium, boron, chromium, and zinc) in groundwater: health risk assessment International Journal of Environmental Science and Technology 9 (1) 153-162

Rasool A, Farooqi A, Masood S and Hussain K 2016 Arsenic in groundwater and its health risk assessment in drinking water of Mailsi, Punjab, Pakistan Human and Ecological Risk Assessment: An International Journal 22 (1) 187-202

Nguyen H Q 2014 Health Risk Assessment for Arsenic Pollution in Groundwater at Ho Chi Minh City VNU Journal of Science: Earth and Environmental Sciences, 30 (1) 50-57
[33] Thuy H T T, Loan T T C, Van C T, Vu V T 2020 Risk assessment due to the presence of radiouclides (U and Th) in groundwater of suburb area, Ho Chi Minh City Meteorology and Hydrology Journal 711 59-65

[34] Li P, Wu J, Qian H, Lyu X and Liu H 2014 Origin and assessment of groundwater pollution and associated health risk: a case study in an industrial park, northwest China Environmental Geochemistry and Health 36 (4) 693-712

[35] US EPA 2012 Support of Summary Information on the Integrated Risk Information System (IRIS)

[36] US EPA 1992 Guidelines for exposure assessment Federal Register 57 (104) 22888-938.

[37] US EPA 2011 Exposure Factors Handbook 2011 Edition (Final Report), US Environmental Protection Agency, Washington DC

[38] Hashmi M Z, Yu C, Shen H, Duan D, Shen C, Lou L and Chen Y 2014 Concentrations and Human Health Risk Assessment of Selected Heavy Metals in Surface Water of the Siling Reservoir Watershed in Zhejiang Province, China Polish Journal of Environmental Studies 23 (3) 801-818

[39] US EPA 1989 Risk assessment guidance for superfund

[40] Wu B, Zhao D Y, Jia H Y, Zhang Y, Zhang X X and Cheng S P 2009 Preliminary risk assessment of trace metal pollution in surface water from Yangtze River in Nanjing Section, China Bulletin of Environmental Contamination and Toxicology 82 (4) 405-409