Evaluation of groundwater quality for domestic purposes and human health risk assessment for arsenic and manganese exposure in Cu Chi district, Ho Chi Minh city, Vietnam

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Abstract:

Water is extremely important to all life currently, the Cu Chi district has been provided with one hundred percent clean water. However, due to long-standing habits and easy extraction, citizens are still using groundwater daily for water consumption and cooking.

Therefore, in this study, the use of groundwater from the middle-upper Pleistocene aquifer in the Cu Chi district of Ho Chi Minh city, for domestic and drinking purposes was investigated. In terms of pH and Fe, NH_4^+, NO_3^-, As and Mn content, data were collected from central water supply stations under the operation of the Centre for Rural Water Supply and Sanitation (CERWASS). Furthermore, samples collected from 94 households and water supply stations were also evaluated for groundwater quality via pH and Fe, As, Hg, Cd, Pb, Cr^{6+} and CN^- concentration. On the other hand, a human health risk assessment for carcinogenic substances (As) and non-carcinogenic substances (Mn) was performed by a variety of assessments including the susceptibility to contamination according to the DRASTIC index, which weights water risks by applying a semi-quantitative model. Because pollution is inevitable with today's modernization and industrialization, these research results contribute to management and control measures deeply needed to achieve and maintain a safe water supply, thereby ensuring the health and safety for the communities in the Cu Chi district.

Keywords: **domestic water, groundwater pollution, middle-upper Pleistocene aquifer, risk assessment.**

Classification number: **2.2**

Introduction

This study investigated the current situation of groundwater use for domestic purposes and consumption. The research team collected data from several centralized water supply stations operated by the CERWASS. The team also conducted surveys and took water samples from 94 households and water supply stations. The evaluation of groundwater quality and its suitability for domestic use was also conducted. The results showed that in terms of raw water quality, most of the samples had low iron (Fe) concentration and pH value. All samples met the National Technical Regulation on Groundwater Quality (QCVN 09-MT:2015/BTMNT). The results showed that, although the assessed risks were minimal, management and control measures are still needed to achieve a safe and sustainable water supply.

In terms of risk assessments, the research team conducted a variety of evaluations: (1) an assessment of the susceptibility to contamination according to the DRASTIC index, (2) an assessment of the water risks by applying a semi-quantitative model, and (3) an assessment of human health risks for both As and Mn. These findings showed that, although the risks were small, management and control measures are sorely needed to achieve a safe water supply as well as to ensure the health and safety of the communities in the area.

Materials and methods

Sampling

The research team collected data from seven water supply stations in the Cu Chi district to assess the groundwater contamination. In order to evaluate raw water quality and assess human health risks of ingestion exposure, water samples were collected and the concentration of heavy metals (Mn and As) from household wells at different depths (-18 to -72 m) within the Upper- and Middle-Upper Pleistocene aquifers were analysed.

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Within the studied region, 94 groundwater samples were collected between November 15, 2019 and November 31, 2019 from household wells located in 17 communes of Cu Chi district, Ho Chi Minh city. The number of samples and their locations are shown below in Figs. 1 and 2.

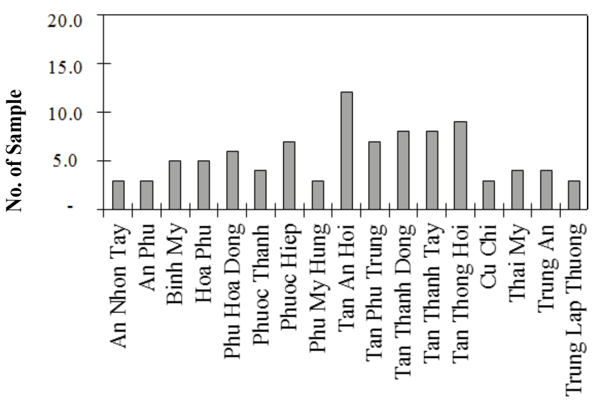

Fig. 1. Diagram showing the number of drilled wells in aquifers at different locations.

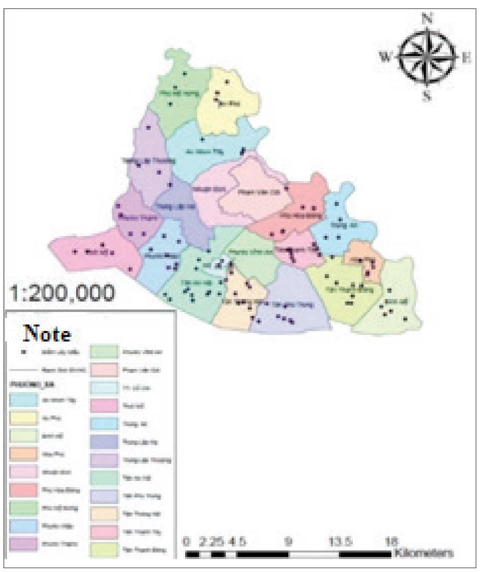

Fig. 2. Sampling locations.

Indicators and analytical procedure

The indicators are the total concentration of Mn and As. The sampling method was followed in accordance with the National Standard TCVN 6663-11:2011 (ISO 5667-11:2009) [1]. Sample storage and handling followed the procedure in the National Standard TCVN 6663-11:2008 (ISO 5667-3:2003).

The analysis was conducted according to the Standard Methods for the Examination of Water and Wastewater, 22nd ALPHA, 2012, and the current National Standards. Experiments and analyses were carried out at the Centre of Analytical Services and Experimentation (CASE), Ho Chi Minh city. Measurements were performed by inductively coupled plasma optical emission spectrometry (ICP - OES) and ammonium (NH_4^+), nitrate (NO_3^-), and nitrite (NO_2^-) were inferred from nitrogen concentration (see Table 1).

Table 1. Summary of analytical methods.

No	Indicators	Unit	Methods	Equipment	Accuracy
1	pH	-	TCVN 6492-2011		
2	Total iron	mg/l	TCVN 6177:1996	ICP – MS/MS	±0.01
3	Manganese	mg/l	SMEWW 3113B:2012	ICP – MS/MS	±0.01
4	Aluminium	mg/l	SMEWW3111B:2012	ICP – MS/MS	±0.01
5	Copper	mg/l	SMEWW3111B:2012	ICP – MS/MS	±0.01
6	Lead	mg/l	SMEWW3113B:2012	ICP – MS/MS	±0.01
7	Total arsenic	mg/l	SMEWW 3114B:2012	ICP – MS/MS	±0.01
8	Cadmium	mg/l	SMEWW 3113B:2012	ICP – MS/MS	±0.01
9	Nitrate	mg/l	SMEWW 4500-NO_3^-.E:2017	DR 5000	±0.001
10	Nitrite	mg/l	SMEWW 4500-NO_2^-.B:2017	DR 5000	±0.001
11	Ammonium	mg/l	SMEWW 4500-NH_4^+.B&F:2017	DR 5000	±0.001

Evaluation methods

Assessment of the groundwater vulnerability to contamination:

The quality of raw water sources in water supply stations was assessed according to the National Standard QCVN 09:2008/BTNMT: National Technical Regulation on Groundwater Quality issued by the Ministry of Natural Resources and Environment.

The quality of treated water is assessed according to the National Standard QCVN 01-1:2018/BYT: National Technical Regulation on Domestic Water Quality issued by the Ministry of Health.

The DRASTIC index (DI) model was used to evaluate the groundwater contamination potential to organic pollution at seven water supply stations. The acronym DRASTIC stands for the seven parameters specific to the water source: the depth to groundwater (D), net recharge of groundwater (R), aquifer media (A), soil media (S), topography (T), impact of the vadose zone media (I), and the hydraulic conductivity of aquifers (C). The vulnerability of groundwater to contamination [2, 3] is as follows:

$$DI = 5D + 4R + 3A + 2S + 1T + 5I + 3C$$

where D: depth (m); R: recharge (mm); A: aquifer; S: soil; T: topography (%); I: impact of vadose zone; and C: conductivity (m/day). The rating scale for groundwater vulnerability is given in Table 2.

Table 2. A rating scale for the groundwater vulnerability to contamination.

No	Rating	Vulnerability category
1	<120	Very low
2	120-139	Low
3	140-159	Moderate
4	160-179	Moderately high
5	180-199	High
6	>199	Very high

Water risk assessment by semi-quantitative model:

The risk assessment of raw water quality was calculated based on the risk quotient (RQ) formula as follows [4]:

RQ = MEC(PEC)/PNEC

where RQ: risk quotient; MEC: measured environmental concentration (mg/l); PEC: predicted environmental concentration (mg/l); and PNEC: predicted-no-effect concentration (mg/l). The risk level rating is classified in Table 3.

Table 3. Classifications for RQ value.

Rating	Low	Moderate	High
RQ value	0.01-0.1	0.1-1	≥1

Human health risk (HHR) assessment [4, 5]:

HHR may be assessed in relation to the potential exposure to toxic substances. The HHR assessment for chemical exposure is usually characterized by the carcinogenic health risks from potential exposure to As and non-carcinogenic health risks from potential exposure to Mn.

Carcinogenic risk assessment:

The method used to estimate the likelihood of a person contracting cancer as a result of exposure to toxic substances in groundwater continuously over the assumption of an average 60-year lifetime can be estimated using the following relationship:

$$RISH_{water} = SF_o \times C_w \times 0.149$$

where SF_0: the cancer potency slope factor for water ingestion (l/mg/kg-day) and C_w: the chemical concentration of chemical in water (mg/l).

Non-carcinogenic risk assessment:

The method used to calculate the probability that a receptor will experience health problems when continuously exposed to a chemical constituent associated with water ingestion over an average 60-year lifetime is presented in reduced form as follows:

$$HAZARD_{water} = \frac{1}{RfD_o} \times C_w \times 0.0639$$

where RfD_0: reference dose for ingestion route (mg/kg-day) and C_w: the chemical concentration of chemical in water (mg/l).

The non-carcinogenic risk associated with potential exposure to a chemical constituent in groundwater can be evaluated in Table 4.

Table 4. The classifications of non-carcinogenic risk assessment results.

Value	$RISH_{water}$ >10^{-4}	10^{-6}< $RISH_{water}$ <10^{-4}	$RISH_{water}$ < 10^{-6}	$HAZARD_{water}$ <1	$HAZARD_{water}$ >1
Risk presumptions	High risk, unacceptable	Moderate risk*	Low risk, insignificant, acceptable	Acceptable risk	Unacceptable risk

*Risks may or may not exist, and these decisions should be based on further analysis.

Results and discussion

Assessment of the vulnerability of groundwater to contamination

The results of Fe content and corresponding pH in samples from the water supply stations tested in the Cu Chi district are shown in Table 5 and Fig. 3.

Table 5. Total Fe concentration and pH.

No	Station	pH	Total Fe (mg/l)
1	An Nhon Tay	6.15	0.0516
2	Binh My	5.42	0.0888
3	Pham Van Coi	5.25	0.0312
4	Phuoc Thanh	4.96	0.0156
5	Thai My	6.08	1.7448
6	Trung An	5.78	0.0468
7	Trung Lap Ha	5.55	0.0624

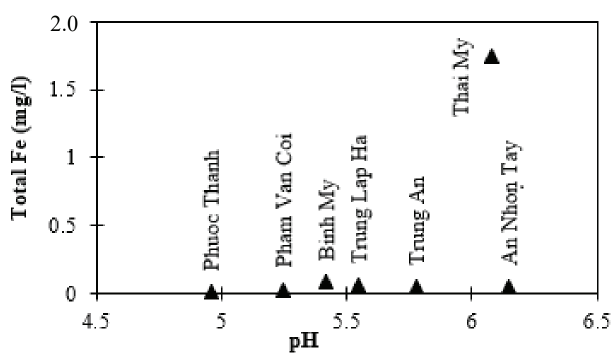

Fig. 3. Total Fe concentration and pH at water supply stations.

In general, the groundwater samples from the water supply stations in the Cu Chi district have a small (almost insignificant) trace of Fe that is widely distributed in the groundwater from the Pleistocene aquifer with a total Fe concentration <0,3 mg/l, particularly at the Thai My station. All samples had low pH values that ranged from 4.96 to

6.15. However, most of them had measured values between a pH level 5.0 and 5.5.

The analysis of the results of ammonium (NH_4^+), nitrite (NO_2^-), and nitrate (NO_3^-) content are shown in Table 6 and Figs. 4 to 6.

Table 6. Ammonium, nitrite, and nitrate concentration at water supply stations.

No	Station	Concentration (mg/l)		
		NH_4^+	NO_2^-	NO_3^-
		<0.1	<1	<15
1	An Nhon Tay	0.05	0.0041	1.6
2	Binh My	0.07	0.0037	2.5145
3	Pham Van Coi	0.1	0.0047	28.1254
4	Phuoc Thanh	0.09	0.0039	4.4115
5	Thai My	0.27	0.0067	2.0522
6	Trung An	0.12	0.0047	3.2737
7	Trung Lap Ha	0.07	0.0043	24.723

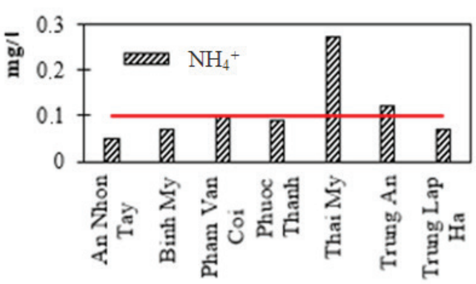

Fig. 4. NH_4^+-N concentration at water supply stations.

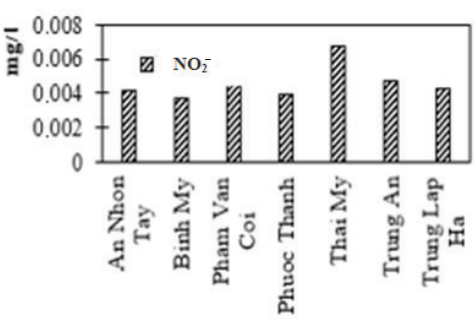

Fig. 5. NO_2^--N concentration at water supply stations.

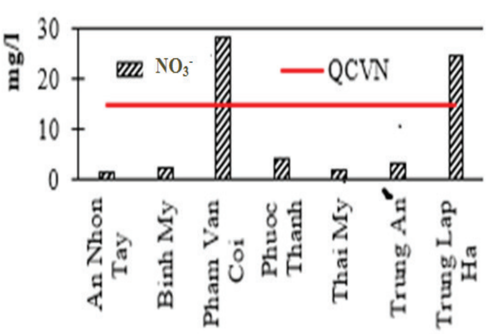

Fig. 6. NO_3^- concentration at water supply stations.

Most of the samples showed the presence of NH_4^+ and NO_3^- but NO_2^- was almost absent. Thus, this region was previously contaminated for a long time but now the contamination has been temporarily reduced, which explains the absence of NO_2^-. However, groundwater contamination has recently increased and continued to spread through this region.

From analysis of the results, a sharp increase in NH_4^+ was observed from the samples taken from Pham Van Coi and Thai My stations. Because the location of the Pham Van Coi station is near the city's cemetery and the Thai My station is close to the Tan Hiep landfill, the risk of contamination from groundwater in these areas is inevitable.

The results of groundwater vulnerability to contamination at the seven water supply stations in the Cu Chi district are shown in Table 7.

Table 7. DRASTIC index of 7 water supply stations in Cu Chi district.

No	Station	D	R	A	S	T	I	C	DRASTIC	Risk to contamination
1	An Nhon Tay	1	9	8	5	10	1	4	102	Very low
2	Binh My	1	9	6	1	10	1	1	79	Very low
3	Pham Van Coi	5	9	8	6	10	1	1	115	Very low
4	Phuoc Thanh	5	9	7	6	10	1	4	121	Low
5	Thai My	1	9	8	1	10	8	4	129	Low
6	Trung An	1	9	8	1	10	1	4	94	Very low
7	Trung Lap Ha	1	9	8	5	10	1	4	102	Very low

The above results of the DI show that the majority of the currently exploited groundwater sources in the area are of very low vulnerability to pollution, but it is necessary to have control measures and close monitoring of groundwater quality in this area to prevent future contamination.

In term of the water quality after treatment at water supply stations, the analysis results of Mn, Hg, Cr^{6+}, and CN^- met the standard limits in QCVN 01-1:2018/BYT for domestic water quality (Table 8).

Table 8. Analysis results of water quality after treatment at water supply stations.

No	Station	Mn (mg/l)	Hg (ppb)	Cr^{6+}(mg/l)	CN^- (mg/l)
1	An Nhon Tay	ND	0.0180	ND	ND
2	Binh My	0.0684	0.0174	ND	ND
3	Pham Van Coi	ND	0.0141	ND	ND
4	Phuoc Thanh	0.0036	0.0257	ND	ND
5	Thai My	0.3492	0.0175	ND	ND
6	Trung An	ND	0.0203	ND	ND
7	Trung Lap Ha	0.06	0.0146	ND	ND

ND: no data.

Risk assessment by semi-quantitative model

The RQ is calculated with PNEC based on QCVN 01-1:2018/BYT and MEC max measured from sampled wells at 94 households in Cu Chi district, Ho Chi Minh city. The results are shown in Tables 9 and 10 below.

Table 9. MEC max at 94 households in Cu Chi district, Ho Chi Minh city.

Depth	pH	Fe (ppm)	Mn (ppm)	Al (ppm)	As (ppm)	Cu (ppm)	Pb (ppm)	Cd (ppm)
-18	4.7	0.00003	0.00008	0.00013	0.00003	ND	0.00175	0.00002
-19	4.6	0.00015	0.00003	0.00012	0.00005	0.00001	0.01121	0.00002
-20	5.5	0.00010	0.00004	0.00015	0.00237	ND	0.00066	0.00001
-22	4.5	0.00017	0.00009	0.00014	0.00004	0.00001	0.00294	0.00003
-24	4.9	0.00003	0.00006	0.00020	0.00001	ND	0.00033	ND
-25	4.9	0.00006	0.00019	0.00005	0.00002	ND	0.00310	0.00009
-26	4.5	0.00003	0.00004	0.00057	0.00025	ND	0.01413	ND
-27	4.5	0.00002	0.00001	0.00001	0.00000	ND	ND	ND
-28	4.6	0.00003	0.00008	0.00028	0.00004	ND	0.00453	0.00001
-30	4.7	0.00019	0.00012	0.00007	0.00003	ND	0.00122	0.00001
-32	5.0	0.00004	0.00004	0.00002	ND	ND	0.02686	0.00006
-34	4.5	0.00002	0.00002	0.00029	ND	ND	0.00460	ND
-35	4.5	0.00005	0.00005	0.00066	0.00015	ND	0.00594	ND
-36	4.3	0.00003	0.00017	0.00007	ND	ND	ND	ND
-40	4.7	0.00012	0.00139	0.00010	0.00002	0.00001	0.00199	0.00011
-42	5.2	0.00059	0.00003	0.00001	ND	0.00002	0.00204	ND
-45	4.6	0.00003	0.00003	0.00006	ND	0.00003	0.00441	ND
-50	5.5	0.00050	0.00001	0.00002	0.00016	ND	0.00021	0.00001
-55	4.9	0.00002	ND	0.00003	ND	ND	0.00030	ND
-57	5.2	0.00007	0.00004	0.00001	ND	ND	0.00026	ND
-60	6.2	0.00030	0.00003	0.00002	0.00009	ND	0.00021	ND
-70	6.7	0.00011	ND	0.00002	0.00194	ND	0.00202	0.00004
-72	5.1	0.00104	0.00008	0.00001	0.00027	ND	0.00020	ND
QCVN 01-1:2018/BYT	7.5	0.3	0.1	0.2	0.01	1.0	0.01	0.03

Table 10. RQ of raw water at 94 households in Cu Chi district, Ho Chi Minh city.

Depth	pH	Fe	Mn	Al	As	Cu	Pb	Cd
-18	0.64855	0.00011	0.00076	0.00066	0.00280	-	0.17480	0.00533
-19	0.63448	0.00050	0.00025	0.00060	0.00500	0.00001	1.12050	0.00500
-20	0.75517	0.00034	0.00040	0.00073	0.23725	-	0.06575	0.00167
-22	0.62586	0.00056	0.00085	0.00071	0.00413	0.00001	0.29438	0.00833
-24	0.67034	0.00011	0.00056	0.00099	0.00120	-	0.03320	-
-25	0.68244	0.00020	0.00190	0.00023	0.00223	-	0.31008	0.02846
-26	0.62069	0.00010	0.00040	0.00285	0.02500	-	1.41300	-
-27	0.62069	0.00007	0.00010	0.00005	-	-	-	-
-28	0.63845	0.00011	0.00075	0.00141	0.00375	-	0.45300	0.00208
-30	0.65147	0.00063	0.00119	0.00034	0.00281	-	0.12225	0.00292
-32	0.68345	0.00013	0.00040	0.00010	-	-	2.68600	0.01833
-34	0.62069	0.00007	0.00020	0.00145	-	-	0.46000	-
-35	0.62069	0.00015	0.00050	0.00330	0.01500	-	0.59350	-
-36	0.59310	0.00010	0.00170	0.00035	-	-	-	-
-40	0.64138	0.00041	0.01392	0.00048	0.00183	0.00001	0.19917	0.03611
-42	0.71724	0.00197	0.00030	0.00005	-	0.00002	0.20400	-
-45	0.62897	0.00008	0.00025	0.00030	-	0.00003	0.44050	-
-50	0.75241	0.00166	0.00008	0.00009	0.01600	-	0.02125	0.00333
-55	0.67862	0.00007	-	0.00015	-	-	0.03000	-
-57	0.71034	0.00023	0.00040	0.00005	-	-	0.02600	-
-60	0.85977	0.00099	0.00033	0.00010	0.00933	-	0.02067	-
-70	0.92414	0.00037	-	0.00010	0.19400	-	0.20200	0.01333
-72	0.70345	0.00347	0.00080	0.00005	0.02700	-	0.02000	-

In the above results, most of the estimated RQ of heavy metals Fe, Mn, As, Al, Cu, and Cd suggest that the environmental risk is very low (RQ<0,01) for all sampling depths. However, As was identified as posing a low risk at depths of -26 m, -35 m, -50 m, and -72 m (0.01<RQ<0.1) and moderate risk at depths of -20 m and -70 m (0.1<RQ<1.0).

In addition, the Pb concentration had a RQ value less than 0.01 at depths of -20 m, -24 m, -55 m, -57 m, -60 m, and -72 m, which indicate very low risk. At depths of -18 m, -22 m, -25 m, -28 m, -30 m, -34 m, -35 m, -50 m, RQ values were within the range of 0.01 and 0.1, which show low risk. At depths of -19 m, - 26 m, -32 m, -40 m, -42 m, -45 m, and -70 m, RQ was in the range of 0.1 and 1.0, which is evaluated as showing moderate risk. At depths of -19 m, -26 m, -32 m, RQ was greater than 1, which is high risk.

The results revealed that the assessment in raw water use related to heavy metal contamination showed low risk, but this does not guarantee health safety for the long-term use of this water without proper treatment.

Table 11. Risk quotient for carcinogenic to As.

Depth	As (ppm)	Carcinogenic risk
-18	0.00003	0.00001
-19	0.00005	0.00001
-20	0.00237	0.00062
-22	0.00004	0.00001
-24	0.00001	0.00000
-25	0.00002	0.00001
-26	0.00025	0.00007
-27	0.00000	0.00000
-28	0.00004	0.00001
-30	0.00003	0.00001
-32	ND	-
-34	ND	-
-35	0.00015	0.00004
-36	ND	-
-40	0.00002	0.00000
-42	ND	-
-45	ND	-
-50	0.00016	0.00004
-55	ND	-
-57	ND	-
-60	0.00009	0.00002
-70	0.00194	0.00051
-72	0.00027	0.00007

Health risk assessment

Carcinogenic risks of the potential exposure to As were estimated for 94 groundwater samples collected from household wells in Cu Chi district, Ho Chi Minh city are shown in Table 11. The non-carcinogenic risks of Mn related to the daily use of groundwater from the 94 households in Cu Chi district, Ho Chi Minh city are shown in Table 12.

Table 12. Risk quotient for non-carcinogenic to Mn.

Depth	Mn (ppm)	Carcinogenic risk
-18	0.00008	0.00097128
-19	0.00003	0.0003195
-20	0.00004	0.0005112
-22	0.00009	0.0010863
-24	0.00006	0.00071568
-25	0.00019	0.0024282
-26	0.00004	0.0005112
-27	0.00001	0.0001278
-28	0.00008	0.0009585
-30	0.00012	0.001517625
-32	0.00004	0.0005112
-34	0.00002	0.0002556
-35	0.00005	0.000639
-36	0.00017	0.0021726
-40	0.00139	0.0177855
-42	0.00003	0.0003834
-45	0.00003	0.0003195
-50	0.00001	0.00009585
-55	ND	-
-57	0.00004	0.0005112
-60	0.00003	0.000426
-70	ND	-
-72	0.00008	0.0010224

Based on the results from the water quality analysis and cancer risk assessment, the groundwater across the 94 households in Cu Chi district had an acceptable quality and As poses no carcinogenic risk or any serious health concerns to the local residents.

The assessment results indicate that the non-carcinogenic risk of Mn through ingestion shows no adverse health effects. Setting priorities of risks from chemical constituent contamination in groundwater according to the semi-quantitative model is shown in the Table 13.

Table 13. The priority risks according to semi-quantitative model.

No.	Chemical constituent	Risk level
1	Mn	No
2	As	No

While the above discussion describes that priority risks are currently non-existent, such risks will eventually become unavoidable in the future at the current rate of industrialization and modernization. The situations of using water from rudimentary treatment procedures or its direct use from sources do not guarantee human health and safety in the future. Therefore, it is necessary to continue to study appropriate mitigation and preventive measures.

Conclusions

The analysis results of pH and total Fe content at 7 water supply stations in the Cu Chi district are very low and ranged within 4.96-6.15, and 0.0156-1.7448, respectively. The NO_2^- parameters have all met the standard limits as given in QCVN 09:2008/BTNMT. On the other hand, the NH_4^+ and NO_3^- content of the water from the Pham Van Coi and Thai My stations exceeded the permitted standard. Because the Pham Van Coi station is located near the city's cemetery and the Thai My station is close to the Tan Hiep landfill, the risk of contamination is inevitable.

After surveying and assessing the vulnerability of groundwater to contamination at seven water supply stations across the Cu Chi district, the water supply shows a high unlikeliness of being contaminated.

However, recent studies indicate that, groundwater reserves and its quality are decreasing due to contamination from surface water and unreasonable exploitation. Therefore, it is necessary to have control measures in place and to continue close monitoring of groundwater quality in this area to prevent future contamination. In addition, greater investment in the construction of underground water treatment systems after exploitation is necessary. The analysis of the concentrations of Fe, As, Mn, Pb, Cd, Hg, Cr^{6+}, and CN^- have met the standard limits in QCVN 01-1:2018/BYT for domestic water quality after treatment at the surveyed water supply stations.

Analysis of the well water from 94 households in the Cu Chi district found that the environmental risk related to heavy metal contamination was not high. However, at certain depths, the RQ coefficient for Pb and As was generally high. Hence, the data showed that the groundwater across the 94 households in the Cu Chi district has acceptable quality and As levels in the water poses no carcinogenic risk or any serious health concerns to local residents.

However, in the future, contamination risks will eventually become unavoidable at the current rate of industrialization and modernization. The water condition from rudimentary treatment procedures or any direct use from natural sources do not guarantee human health and safety in the future. Therefore, it is essential to further study appropriate mitigation and preventive measures.

The results of this work are a premise for management as well as further research of the mitigation and prevention of water contamination.

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