

Assessment of Groundwater Quality in Quaternary Sediments of Da Nang City in the Period 2000-2017

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Abstract: Groundwater in Quaternary sediments of Da Nang city has been saline, the area of saline water is increasing. Salt water (total mineralization > 1 g/l) is distributed along big rivers such as Han River, Cam Le River, Vinh Dien River, Cau Do River and Cu De River in Holocene and Pleistocene aquifers. Freshwater, with the water mineralization of less than 1 g/l, widely distributed in the study area, was previously contaminated by Fe but now it is polluted by ammonium at some places in Hoa Hiep Bac ward (Lien Chieu district) and some places in Ngu Hanh Son district in the aquifers of Holocene and Pleistocene, polluted by nitrite in Cam Ne village, Hoa Tien commune (Hoa Vang district) in the Pleistocene aquifer, and polluted by Fe in Hoa Lien commune (Hoa Vang district) and at some places in Ngu Hanh Son district in the Holocene and Pleistocene aquifers.

Key words: groundwater, Da Nang, fluctuations, quality

1. Introduction

Da Nang is a coastal province in the central region of Vietnam, with abundant natural potential, Da Nang has exploited natural resources, including water resources, to serve living and production. Currently, domestic water supply for the city is mainly from Cau Do and San Bay water plants, which collect raw water from Yen and Cau Rivers, providing about 97% of the total capacity; the rest comes from two small factories. In Son Tra and Hai Van, we take spring water from the mountain. The surface water supply for Da Nang city is limited, so it is necessary to have an overall assessment of the quality fluctuations of groundwater in Quaternary sediments from 2000 to 2017, with the optimal solution to use groundwater and to reduce pressure on surface water in the city.

2. Material and Methods

2.1 Research Data

2.1.1 Inherited Data from Hanoi University of Mining and Geology in 2000

The number of samples is 36, analyzing the following criteria:

- Comprehensive analysis: pH, total mineralization, Na⁺, K⁺, Ca²⁺, Mg²⁺, HCO₃⁻, SO₄⁻², Cl⁻, NH₄⁺, NO₂⁻, NO₃⁻, CO₃⁻², total Fe;
- Micro-analysis: Co, Cu, As, Al; heavy metals such as: Hg, Pb, Pt, Ni...;
- Analysis of the major environmental indicators such as COD, BOD, CN⁻, SS, DO...

2.1.2 Inherited data from Department of Natural Resources and Environment of Da Nang in 2011

- Results of physical and chemical analyses of groundwater samples:

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- * 18 groundwater samples were analyzed for pH, hardness, total mineralization, Cl^- , SO_4^{2-} , NO_3^- , NH_4^+ , NO_2^- , $\sum\text{Fe}$, Al;
- * 21 groundwater samples analyzed for As, Cd; 23 groundwater samples were analyzed for Cu; 16 groundwater samples were analyzed for CN^- , phenol;
- * 15 groundwater samples were analyzed for Coliform, Fecal Coliform; 9 groundwater samples were analyzed for Hg, Co;
- * 7 groundwater samples were analyzed for Pb.
- Survey on the depth and the static water level in the qh aquifer of 83 wells in the area.
- Survey on the bore depth, static water level, flow rate, lowering value and specific flow rate of 25 boreholes in the area.

2.1.3 Results of physical and chemical analyses of water samples at the Laboratory of the Institute of Geography, Vietnam Academy of Science and Technology

- December, 2016: 100 groundwater samples were analyzed for ToC, pH, EC, Cl^- và SO_4^{2-} .
- April, 2017: 100 groundwater samples were analyzed for ToC, pH, EC, Cl^- and SO_4^{2-} ; in which 14 groundwater samples were further analyzed for Na^+ , K^+ , Ca^{2+} , Mg^{2+} , NH_4^+ , NO_2^- , NO_3^- , hardness, TDS, COD, Pb, Fe).
- July, 2017: 100 groundwater samples were analyzed for ToC, pH, EC, Cl^- and SO_4^{2-} ; in which 7 groundwater samples were further analyzed for Na^+ , K^+ , Ca^{2+} , Mg^{2+} , NH_4^+ , NO_2^- , NO_3^- , hardness, TDS, COD, Pb, Fe).

2.1.4 Geophysical measurement results performed by experts from the Institute of Geophysics, Vietnam Academy of Science and Technology

- December, 2016: 200 measurement points
- April, 2017: 200 measurement points
- July, 2017: 200 measurement points

2.2 Research Methods

- Inheritance method: Inheriting research results on groundwater quality before 2016.
- Field survey method: Groundwater sampling at locations with signs of pollution and salinity: 300 groundwater samples in districts of Da Nang city.
- Sample analysis method: is used to analyze the physical and chemical properties of water samples taken during field surveys, as a basis for assessing water quality in the study area compared to Vietnam Standards QCVN 09:2015-MT/BTNMT (QCVN).
- Method of vertical electrical sounding: is used to measure the resistance of rock and soil, in order to determine the geological structure, the saline-freshwater boundary of groundwater in aquifers in Quaternary sediments.
- Modeling method: the numerical modeling method is used with a combination of Modflow and Seawat models to determine the current status of saline-freshwater boundaries of aquifers and to forecast for the future based on scenarios.

3. Results and Discussion

There are 3 aquifers in Quaternary sediments: aquifer in undivided Quaternary sediments (q), Holocene aquifer (qh) and Pleistocene aquifer (qp). However, there are only two aquifers qh and qp which are significant for water supply for living and irrigation, so the author only mentioned fluctuations in water quality of qh and qp aquifers in this paper.

3.1 Current Situation of Groundwater Quality for Living

3.1.1 Holocene Aquifer

(1) Physical properties

The groundwater of qh aquifer in Da Nang city is mostly colorless, odorless, and tasteless. However, some places are polluted by organic compounds, the water is green with the stench such as in La Bong, Cam Ne, Hoa Tien, Hoa Vang and Tran Dinh Tri street (Lien Chieu district) [1, 2]. Some places are polluted by iron,

the water is yellow such as in La Chau village, Hoa Khuong commune; Dong Hoa village, Phong Nam village, Hoa Chau commune (Hoa Vang district); Phan Van Dinh, Phan Van Truong, Tran Dinh Tri, Bau Mac and Tot Dong (Lien Chieu district).

The pH of groundwater ranges from 7.0-7.68, within the limits of Vietnam Standards 09-MT:2015/BTNMT (QCVN).

(2) Hardness

Hardness of the water ranges from 20-1100 mg CaCO₃/l; the places with considerable hardness exceeding QCVN are Hoa Lien commune (Hoa Vang district), Le Huy Cat street and K20 (Ngu Hanh Son district) [3, 4, 6].

(3) Total Mineralization M (g/l):

The total mineralization of groundwater ranges from 0.21-3.24 g/l (in particular, up to 10.75 g/l in the Hoa Hiep area, Lien Chieu district).

(4) Nitrogen compounds:

+ Ammonium (NH₄⁺): Groundwater has NH₄⁺ content, calculated according to N, ranging from 0 - 2.97 mg/l, in which 3/100 analysis samples have NH₄⁺ content exceeding QCVN, namely water samples in Hoa Hiep Bac ward (Lien Chieu district) and some places in Ngu Hanh Son district. In these areas, water has shown signs of contamination by nitrogen compounds, where the highest value (2.97 mg/l) belongs to the NHS10 sample at the well in Le Huy Cat Street in Ngu Hanh Son district.

+ Nitrite (NO₂⁻): Groundwater has NO₂⁻ content, calculated according to N, from 0.004 to 0.63 mg/l, within the limits of Vietnam Standards.

+ Nitrate (NO₃⁻): Groundwater has NO₃⁻ content, calculated according to N, ranging from 0.06 to 12.8 mg/l, within the limits of Vietnam Standards.

Groundwater of Holocene aquifer in the study area has a part of freshwater that can be used for living. However, it is polluted by ammonium in some places in Lien Chieu and Ngu Hanh Son districts.

(5) Microelements:

+ Lead (Pb): Lead content in groundwater ranges from 0.011 - 0.088 mg/l, within the limits of Vietnam Standards.

+ Iron (Fe): Total iron content varies from 1.79-125.4 mg/l. The places having groundwater contaminated with iron are Hoa Lien commune (Hoa Vang district) and some areas in Ngu Hanh Son district [4, 6].

(6) Chlorine ion (Cl⁻):

Cl⁻ ion content varies from 4.3 to 2158.4 mg/l. The areas with Cl⁻ ion content greater than 250mg/l coincide with the water areas of M > 1g/l, which are the Cu De estuary, the right bank of Cau Do River, along Cam Le and Han Rivers, some places in Thanh Khe and Ngu Hanh Son districts.

(7) Conclusion

In general, groundwater in some places are polluted by ammonium such as in Hoa Hiep Bac ward (Lien Chieu district) and some places in Ngu Hanh Son district, are polluted by iron such as in Hoa Lien commune (Hoa Vang district) and some places in Ngu Hanh Son district.

The saline area of the qh aquifer in Da Nang city is distributed at Cu De estuary, on the right bank of Cau Do River, along Cam Le and Han Rivers, at some places in Thanh Khe and Ngu Hanh Son districts.

3.1.2 Pleistocene Aquifer

(1) Physical Properties

Groundwater is mostly colorless, odorless, and tasteless, but in some places the water is polluted by organic compounds, the water has a stench such as in Cam Ne village, Hoa Tien commune, Hoa Vang district.

The pH of groundwater ranges from 7.7 to 8.9.

(2) Hardness

The groundwater has a hardness ranging from 70 to 705 mg CaCO₃/l, Hoa Lien commune (Hoa Vang district) has the considerable hardness of 705 mg CaCO₃/l, exceeding QCVN.

(3) Total mineralization M (g/l)

The total mineralization of water in wells varies from 0.13 to 0.51 g/l.

(4) Nitrogen Compounds

- Ammonium (NH₄⁺): Groundwater has NH₄⁺ content, calculated by N, ranging from 0-3.54 mg/l, water is polluted by ammonium in some places in Ngu Hanh Son district, especially at the well in the resettlement area in Ngu Hanh Son district.
- Nitrite (NO₂⁻): Groundwater has NO₂⁻ content, calculated according to N, ranging from 0.002-4.4 mg/l [3, 4], the groundwater shows signs of nitrite pollution (4.4 mg/l) in the area of Cam Ne village, Hoa Tien commune (Hoa Vang district), exceeding QCVN.
- Nitrate (NO₃⁻): NO₃⁻ content of groundwater, calculated according to N, ranges from 0.05 to 0.12 mg/l [3, 4], within the limits of Vietnam Standards.

Groundwater is contaminated by ammonium in some places in Ngu Hanh Son district, by nitrite in some places in Hoa Tien commune (Hoa Vang district).

(5) Microelements

- Lead (Pb): Lead content in groundwater in the study area ranges from 0.014-0.066 mg/l, within the permitted limits of QCVN.
- Iron (Fe): Iron content varies from 3.29-5.27 mg/l. Water is polluted by iron in some parts of Hoa Lien commune (Hoa Vang district), exceeding QCVN.

(6) Chlorine ion (Cl⁻):

Cl⁻ ion content ranges from 4.0-2428.2 mg/l, the areas with Cl⁻ ion content greater than 250 mg/l coincide with the areas with M > 1g/l, which are along big rivers (Han River, Cam Le River, Vinh Dien River, Cau Do River and Cu De River).

(6) Conclusion

The groundwater of the Pleistocene aquifer in the study area has a portion of freshwater that can be used for living, but the groundwater is polluted by

ammonium in the resettlement area in Ngu Hanh Son district, polluted by nitrite in Cam Ne village, Hoa Tien commune (Hoa Vang district), and polluted by iron in Hoa Lien commune (Hoa Vang district).

The saline water area of the qp aquifer is along major rivers (Han River, Cam Le River, Vinh Dien River, Cau Do River and Cu De River).

3.2 Current Situation of Groundwater Quality for Irrigation

The Na⁺ ion content is smaller than the Cl⁻ content in water samples, so K_a is determined by the following empirical formula:

$$K_a = \frac{288}{5rCl^-}$$

r – Cl⁻ content (mgdl/l)

According to the value of K, groundwater is divided into:

- K_a ≥ 18: good quality
- K_a = 18-6: satisfactory for irrigation
- K_a < 5.9: unsatisfactory for irrigation

Groundwater in Da Nang city has irrigation coefficient K_a from 1.0 to 476 [3, 4], commonly from 20 to 50 (Table 1), indicating that the groundwater can be used for irrigation. However, there are some water samples with K_a < 5.9, which are unsatisfactory for irrigation.

3.3 Current Situation of Saline Intrusion and Pollution of Groundwater

3.3.1 Holocene Aquifer

The qh aquifer is hydrologically related to the major river systems in the region, so it is affected by saline water in the rivers. Along the Cu De River, within 6km from the sea, the groundwater is saline with a salinity of 1.0-10.75 g/l [4, 5, 7]. Saline area is distributed as follows: at Cu De estuary, the saline water area is about 15 km²; on the right bank of Cau Do and Cam Le Rivers, the saline water area is about 40 km². In these regions, groundwater is affected by both saline intrusion due to the rivers and saline intrusion of the

sediment below. Along the Han River, the groundwater is saline with an area of 5 km². The chemical

composition of groundwater in this aquifer is mainly–sodium chloride.

Table 1 Irrigation coefficient Ka.

No.	Water samples	Ka	Quality	Note
1	LC14	50	Good quality for irrigation	
2	LC15	476	Good quality for irrigation	
3	HV34	1	Unsatisfactory for irrigation	Hoa Ninh 5 resettlement area, Hoa Lien commune, Hoa Vang district
4	HV35	36	Good quality for irrigation	
5	HV38	1	Unsatisfactory for irrigation	Thong Huu Phuoc, Hoa Lien commune, Hoa Vang district
6	HV39	41	Good quality for irrigation	
7	HV40	44	Good quality for irrigation	
8	NHS10	1	Unsatisfactory for irrigation	Le Huy Cat street, Ngu Hanh Son ward
9	NHS11	60	Good quality for irrigation	
10	NHS12	26	Good quality for irrigation	
11	NHS17	2	Unsatisfactory for irrigation	Ngu Hanh Son ward
12	NHS18	42	Good quality for irrigation	
13	NHS22	18	Satisfactory for irrigation	
14	CL17	36	Good quality for irrigation	
15	M3.1	49	Good quality for irrigation	
16	T12	50	Good quality for irrigation	
17	M5.1	31	Good quality for irrigation	
18	M5.2	28	Good quality for irrigation	
19	M5.3	31	Good quality for irrigation	
20	NNHT03	50	Good quality for irrigation	
21	NCCN01	115	Good quality for irrigation	

In addition, in some places in Thanh Khe and Ngu Hanh Son districts, the total mineralization varies from 1,037-1,434 g/l [4-7]. The freshwater is contaminated by ammonium in Hoa Hiep Bac ward (Lien Chieu district) and some places in Ngu Hanh Son district, polluted by iron in Hoa Lien commune (Hoa Vang district) and some places in Ngu Hanh Son district.

3.3.2 Pleistocene Aquifer

The groundwater in the qp aquifer has suffered from saline intrusion according to 2 mechanisms:

Firstly, modern saline water from the estuaries and sea in the direction of horizontal intrusion;

Secondly, the potential saline intrusion due to previous marine transgression.

The saline area of the qp aquifer is distributed along the major rivers (Han River, Cam Le River, Vinh Dien

River, Cau Do River and Cu De River).

The freshwater of qp aquifer can be used for living, except for some places which are contaminated by ammonium such as resettlement area in Ngu Hanh Son district, polluted by nitrite such as Cam Ne village, Hoa Tien commune (Hoa Vang district), and polluted by iron such as Hoa Lien commune (Hoa Vang district).

3.4 Fluctuation of Groundwater Quality in Da Nang City

3.4.1 Holocene Aquifer

In the 2000s, content of NH₄⁺ calculated according to N usually ranged from 0.1 to 0.25 mg/l, especially only one sample had NH₄⁺ content exceeding QCVN in Lien Chieu district [1, 2]; but until now, NH₄⁺ content in N tends to increase, ranging from 0-2.97 mg/l, in

which 3/100 analytical samples have NH_4^+ content exceeding QCVN, in Hoa Hiep Bac ward (Lien Chieu district) and some places in Ngu Hanh Son district, groundwater is polluted by ammonium.

In the 2000s, NO_2^- content in N ranged from 0 to 4.12 mg/l, in which 8/23 (35%) samples in Lien Chieu area exceeded the permissible limits of QCVN [1, 2], unsatisfactory for living. But from 2010 to present, there was no sign of nitrite contamination in the study area.

In the 2000s, the groundwater in Lien Chieu area was contaminated by iron. Total iron content ranged from 8.28-39.04 mg/l, exceeding the permissible limit of QCVN [1, 2, 4, 5]. From 2010 up to now, the groundwater in the qh aquifer has a variable content of iron with a wider amplitude than before, from 1.79-125.4 mg/l, the area contaminated by iron also expanded more than before including Hoa Lien commune (Hoa Vang district) and some areas in Ngu Hanh Son district.

The area of saline water is larger than in the previous period. The saline area is distributed in the South of Cu De River with an area of about 4 km², the second area extends along the coast of Lien Chieu and Ngu Hanh Son districts [2, 6]. In 2010, the area of saline intrusion of the qh aquifer expanded, distributed at the mouth of Cu De River with about 15 km². Along the Cu De River, within 6 km from the sea, the groundwater has the salinity from 1.0 to 10.75 g/l. On the right bank of Cau Do and Cam Le Rivers, the saline water has an area of 40 km², the total mineralization varies from 1.0 to 5.03 g/l. In these regions, the groundwater is influenced by both saline intrusion due to the rivers and saline intrusion of the sediment below. Along the Han River, the saline water has an area of about 5 km². The chemical composition of groundwater is mainly sodium chloride [4, 5, 8]. In 2017, there were additional small saline regions in Ngu Hanh Son area.

3.4.2 Pleistocene Aquifer

In the 2000s, the NH_4^+ content of groundwater in the qp aquifer, calculated according to N, usually ranged

from 0.1 to 0.25 mg/l, within the permitted limits of QCVN [1, 2]; up to now, NH_4^+ content calculated by N ranges from 0-3.54 mg/l, the water has signs of ammonium pollution in some places in Ngu Hanh Son district, where the highest value (3.54 mg/l) belongs to NHS11 sample at the borehole in resettlement area in Ngu Hanh Son district [4, 6].

In the 2000s, the groundwater in the qp aquifer of the study area had NO_2^- content, calculated according to N, varying from 0 to 3 mg/l, in which 25% of samples in Lien Chieu area exceeded the permissible limits of QCVN [1, 2], unsatisfactory for living. By 2017, the groundwater in the qp aquifer has NO_2^- content ranging from 0.002-4.4 mg/l, the groundwater is contaminated by nitrite (4.4 mg/l) in the area of Cam Ne village, Hoa Tien commune (Hoa Vang district), exceeding the permissible limit of QCVN.

In the 2000s, the groundwater of qp aquifer in Lien Chieu area was contaminated by iron. The total iron content ranged from 7.05 to 19.1 mg/l, exceeding the permitted threshold of QCVN [2, 3]. So far, the groundwater has an iron content varying from 3.29 to 5.27 mg/l. The water shows signs of iron pollution in some parts of Hoa Lien commune (Hoa Vang district), exceeding the permissible limit of QCVN.

The saline area of the qp aquifer in the 2000s was distributed in Cu De River and up to a depth of 50 m, the saline area was expanded and deeply absorbed by vertical faults, the second are extended along the coast in Lien Chieu and Ngu Hanh Son districts [1-3]. By 2010 and 2013, the saline area of the qp aquifer was distributed along major rivers (Han River, Cam Le River, Vinh Dien River, Cau Do River and Cu De River) [2, 3]. Up to now, the saline area has fluctuated in the saline-freshwater boundary, but insignificantly [4].

4. Conclusion

Da Nang city area has Holocene and Pleistocene aquifers which are significant for living, but have been partially saline.

The freshwater, with mineralization < 1 g/l, is widely distributed in the study area, but there are some places polluted by ammonium, nitrite and Fe as follows:

Ammonium pollution occurs in Hoa Hiep Bac ward (Lien Chieu district) and some places in Ngu Hanh Son district in Holocene and Pleistocene aquifers [4, 6].

Nitrite pollution occurs in Cam Ne village, Hoa Tien commune (Hoa Vang district) in Pleistocene aquifer.

Iron pollution occurs in Hoa Lien commune (Hoa Vang district) and some places in Ngu Hanh Son district in Holocene and Pleistocene aquifers.

The saline water with $M > 1$ g/l is distributed along the big rivers such as Han River, Cam Le River, Vinh Dien River, Cau Do River and Cu De River into ranges of 5-40 km² [4, 7, 8] in the Holocene and Pleistocene aquifers.

The saline water area in the qh and qp aquifers tends to expand from 2000 to 2010, up to now the saline-freshwater boundary has little changed, but some small saline areas appeared in Ngu Hanh Son district [4, 6].

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