Mineralia Slovaca, Web ISSN 1338-3523, ISSN 0369-2086, https://doi.org/10.56623/ms.2022.54.1.5
54, 1 (2022), 69 – 80,

Relation of groundwater quality and peat deposits in Tay Ninh province, Vietnam

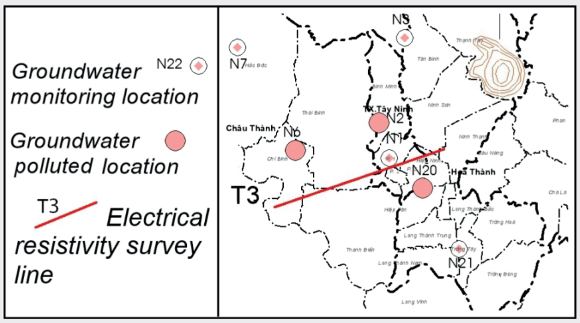
HUYNH PHU[1], LE CANH TUAN[2*], NGUYEN LY NGOC THAO[1] and HUYNH THI NGỌC HAN[3]

[1] HUTECH University; 475A Dien Bien Phu Street, Ward 25, Binh Thanh District, Ho Chi Minh City, Vietnam; h.phu@hutech.edu.vn; nln.thao@hutech.edu.vn
[2] Hanoi University of Natural Resources & Environment; 41A Phu Dien Street, Ward Phuc Dien, Bac Tu Liem District, Hanoi City, Vietnam; lctuan@hunre.edu.vn
[3] Hochiminh City University of Natural Resources & Environment; 236B Le Van Sy Street, Ward 1, Tan Binh District, Ho Chi Minh City, Vietnam; htnhan_ctn@hcmunre.edu.vn
***** Correspondence: lctuan@hunre.edu.vn; Tel.: +84-983806463

Abstract: The groundwater quality of Tay Ninh province was studied applying monitoring of 24 wells from 2016 to 2019. Based on this research there were determined 8 sites with very bad water quality, mostly due to the low pH index, high iron and ammonium contents. The remaining 16 wells preserve very good water quality. To determine the relationship between groundwater quality and peat deposits, the authors studied the map of these deposits in Tay Ninh province and compared it with monitoring points. The results show source of pollution mainly related to peat deposits and human activity. Due to the sustainable development, Tay Ninh province needs planning and the reasonable exploitation of the groundwater in the next 30–50 years, as well as the water resources partition and their management in each district.

Key words: groundwater, groundwater protection, Groundwater Quality Index (GWQI), Tay Ninh Province

Graphical abstract



Highlights

- The degraded groundwater quality in Tay Ninh province, Vietnam, is related on the peat deposits and the human activity.
- Location of monitoring sites was based on resistivity profiling results, revealing 7 aquifers – 6 in Cenozoic sediments and 1 in fractured Mesozoic-Paleozoic rocks. Altogether 11 parameters were registered in monitoring sites.

1 Introduction

The study area in Tay Ninh province is located in Southwest Vietnam in polygon approximately between North latitudes 10° 57′ 24.86″ to 11° 45′ 41.09″ and East longitudes 105° 48′ 5.09″ to 105° 51′ 20.75″ as shown in Fig. 1. Water here is extremely important for sustainable development, people's lives and health, so the water demand increases day by day. To guarantee the sufficiently high water quality, the monitoring of water quality is extremely necessary. The authors have studied groundwater quality in Tay Ninh Province from 2016 to 2019. Their aim was the determination the relationship between groundwater quality and mineral extraction (peat extraction in Tay Ninh province, Vietnam). The analyses results of water samples were evaluated on the basis of drinking water standard of Vietnam Ministry of Health and handled by Groundwater Quality Index (GWQI). The conclusions of the authors about the water quality serve to Sustainable Development on Water Resources in Tay Ninh Province.

2 Materials and methods

2.1 Sampling collection methods

The material presented in article is a result of groundwater research in Tay Ninh province from 2016 to 2019. Collected material was processed applying standard methodology and the referred literature aiming to clarify the distribution rules of aquifers and confining beds, determination of groundwater reserves and factors affecting water quality (Chaterjee & Raziuddin, 2002; Dinh, 1992; Dung, 2005; Hoa et al., 1992; Hung, 1999; Institute of Environmental Technology Promotion and Water Resources Phu My, 2019; Mary & William, 1992; Vietnam Environment Administration, 2011; Vietnam Environment Administration, 2010; Loke, 2015).

During study of groundwater quality in Tay Ninh province, the continuous monitoring and sampling in 2016–2019 of 24 wells, taking and analysing 72 samples was done (Tab. 1). The sample analysis results were compared with the indicators of clean water quality according to Vietnam standards 01-1: 2018 / MOH) (Tab. 2).

In order to fulfil the aforementioned objectives, we used the study methods as described in following subchapters.

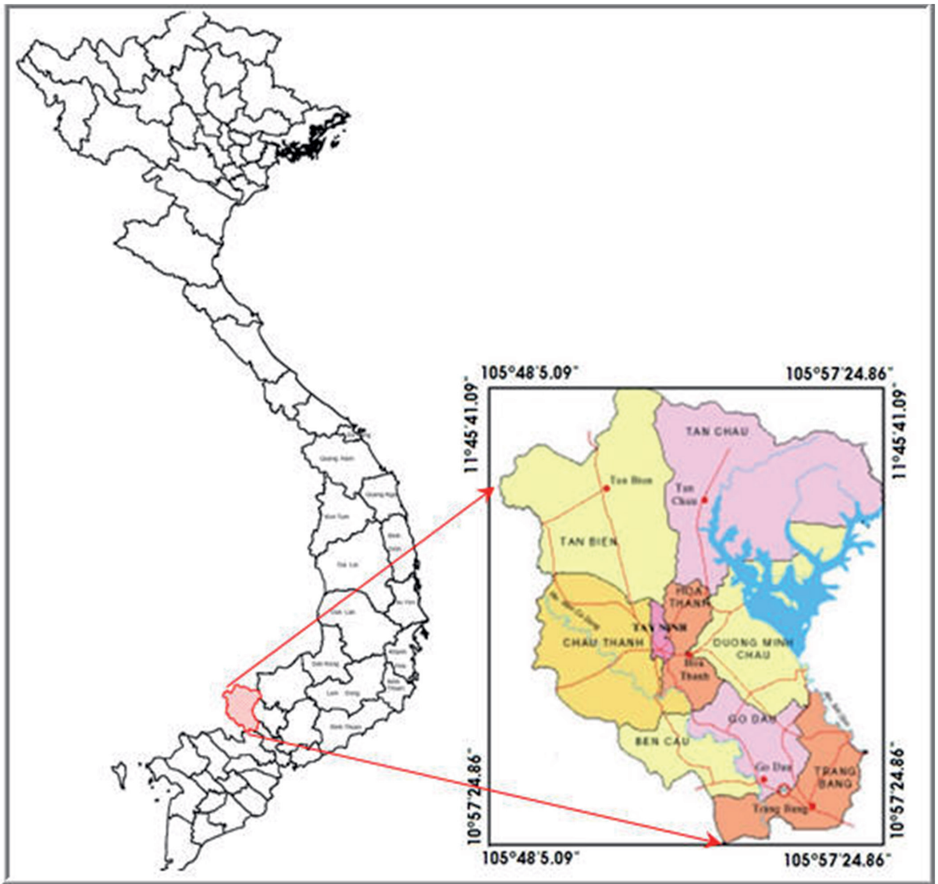


Fig 1. The Tay Ninh province located in the Southwest region of Vietnam.

Tab. 1
List of monitoring wells and number of samples.

N°	Monitoring location	Symbol	Samples	N°	Monitoring location	Symbol	Samples
1	Thai Chanh Preschool – 125, 30/4, P2	N1	3	13	Mr. Le Thanh Truc, Go Dau town	N13	3
2	Mr. Dang Van Hoa, Giong Tre village, Binh Minh commune	N2	3	14	Ms. Nguyen Thi Thuong, Hoa Binh village, Hòa Hiệp commune	N14	3
3	Mr. Tran Van Sy, Tân Bình commune	N3	3	15	Mr. Tran Van Luy, Thạnh Nam village, Thanh Tay commune	N15	3
4	Ms. Nguyen Thi Tam, Ben Cau town	N4	3	16	Mr. Truong Cong Khuyen, Thanh Phu village, Thanh Binh commune	N16	3
5	Mr. Ngo Van Luan, Bến Cầu town	N5	3	17	Mr. Bui Minh Dung, Tan Hiep commune	N17	3
6	Mr. Nguyen Van Đu, Chau Thanh town	N6	3	18	Mr. Nguyen Van Hanh, Suoi Ngo commune	N18	3
7	Ms. Luong Thi Thang, 313 – An Loc village, An Co commune	N7	3	19	Mr. Cu Thien Su, Suoi Day commune	N19	3
8	Phuoc Vinh Commune People´s Committee	N8	3	20	Ms. Truong Thi Sang, Hoa Thanh town	N20	3
9	Mr. Đoan Van Hung, Suoi Đa commune	N9	3	21	Ms. Vo Thi Kim Khuya, Truong Đong commune	N21	3
10	Mr. Trinh Van Tinh, Phuoc Minh commune	N10	3	22	An Tinh commune clinic	N22	3
11	Mr. Tran Van Niem, Duong Minh Chau town	N11	3	23	Phuoc Lam pagoda, Trang Bang town	N23	3
12	Mr. Nguyen Van Chanh, Phuoc Đong commune	N12	3	24	Mr. Nguyen Quang Trung, An Hòa commune	N24	3

2.2 Geophysical methods

The resistivity survey followed the methodology developed by Wenner (Loke, 2015, http://web.gps.caltech.edu/classes/). The layout diagram of the multipolar Wenner system, the order of measurement and recording of the outdoor resistivity survey values are described in Figure 2. The electrodes were evenly arranged along a straight line with the initial distance (measurement step) of 20 m. Extending the multipolar system on the measuring profile (to the left, to the right, or both sides), we obtained a sequence of measured resistivity survey values along the study route. The results allow to determine the aquifers.

We have designed 5 sub-parallel geophysics measurement lines (Fig. 3). The geophysics measurement results were verified by boreholes. See line T1 through borehole N15 (Fig. 2A) and lithological profile constructed owing to results of geophysical measurements (Fig. 2B)

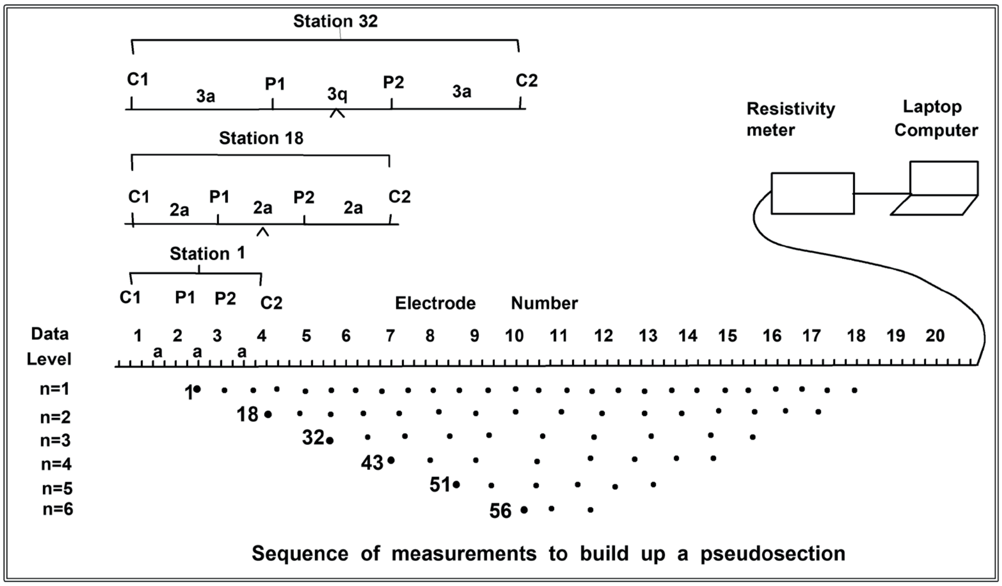


Fig. 2. The arrangement of electrodes for a 2-D electrical survey.

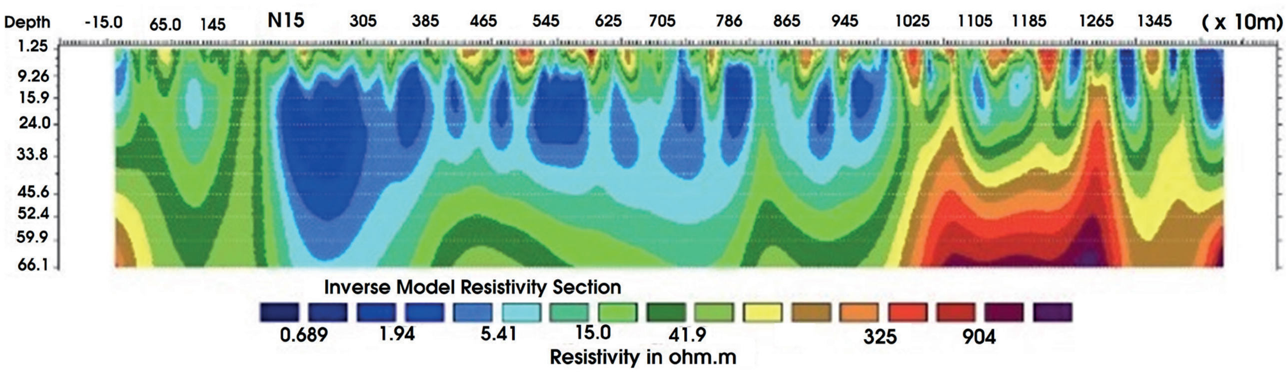


Fig. 2A. The results of geophysical measurement passing through the borehole N15.

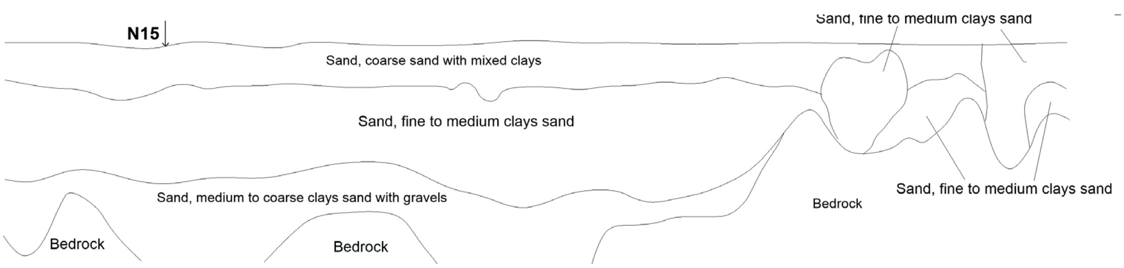


Fig. 2B. Lithology revealed by geophysical profiling.

2.3 Methods of boreholes location and their moni-toring

The location of the boreholes was based on results of geophysical methods. Besides we collected data about the amount of rain, amount of vaporizing, flow, the flow of water outlet points, as well as oscillated water table. Monitoring works in pits and boreholes, including pump and suck water experiments, helped us to determine relatively accurately the total amount of groundwater that can be exploited in the entire study area. For Tay Ninh Sustainable Development and Environmental Protection, the groundwater exploits must ensure, the total amount of the groundwater exploit is always less than or equal to the amount of water replenished for groundwater, and can be calculated by the following water balance equation:

$$Vkt \leq 365 \times 103 \times S \times R; \; R = kf \times (I - ET - SR)$$

Where: R is the average amount of replenishment groundwater/year,

Vkt is the total amount of exploitable groundwater, m^3/year,

kf = 0.7 ÷ 0.85

is the coefficient for the amount of water due to absorption by vegetation,

I is the average rainfall/year,

ET is the average evaporation/year,

SR is the average amount of flow on the face/year. SR is determined from digital hydrological models (mm/day). S is the acreage of the study area (km^2).

Precipitation total I and evapotranspiration total ET data are provided by national meteorological and hydrological monitoring stations.

The water samples were taken from water for drinking water sources such as wells, boreholes, located in Tay Ninh province. Method of groundwater sampling was done according to the guidance of Vietnamese standards: 6663-11: 2011 (ISO 5667-11: 1991) (Department of Environmental Management – Ministry of Health, 2016; Ministry of Health, 2009; Ministry of Natural Resources and Environment, 2015; National standards, 2011) (Tab. 2).

2.4 Sample analysis methods

Water samples were analysed for 11 criteria: pH, TDS, Hardness, $CaCO_3$, Chemical Oxygen Demand (COD), Ammonia ($N–NH_4^+$), Nitrate ($N–NO_3^-$), Fe, Chloride, Pb, *Escherichia coli* and Coliform bacteria (Standards and methods – Tab. 2).

Convenient Portable pH Meter for Wherever Work Takes-ST300 (STARTER)

Measurement Range
0–100 °C; 0.00–14.00 pH; 0–1999 mV

Measurement Resolution:
0.1 °C; 0.01 pH; 1 mV

Accuracy:
± 0.5 °C; ± 1 mV; ± 0.01 pH

Samples were analysed at National Lab – Phumytech (Tab. 2) (Ministry of Health, 2018; Ministry of Natural Resources and Environment, 2015).

Tab. 2
Parameter and Standard (Ministry of Health, 2009).

N°	Parameter	Units	Standard and methods	Vietnamese standards 01-1: 2018/MOH
1	pH	–	TCVN 6492: 2011	6.0–8.5
2	TDS	mg/L	TCVN 9462: 2012 ASTM D5284-09	1 000
3	Hardness, $CaCO_3$	mg/L	TCVN 6224: 1996	300
4	Chemical Oxygen demand (COD)	mg/L	SMEWW 5220C: 2012	2
5	Amoni ($N–NH_4^+$)	mg/L	SMEWW 4500-NH_3.B&F: 2012	0.3
6	Nitrate ($N–NO_3^-$)	mg/L	SMEWW 4500-NO_3^-.E: 2012	2
7	Fe	mg/L	SMEWW 3111B: 2012	0.3
8	Chloride	mg/L	TCVN 6194: 1996	0.2–1
9	Pb	mg/L	SMEWW 3113B: 2012	0.01
10	*Escherichia coli*	CFU/100 ml	SMEWW 9222G: 2012	< 1
11	Coliform bacteria	CFU/100 ml	TCVN 6187-2: 1996	< 3

2.5 Assessment of groundwater quality with concern to drinking water standards

The analysis results are compared with the allowable limit according to Vietnamese standards 01-1: 2018/MOH, regulated by the Ministry of Health on National Technical Regulations on clean water quality used for domestic purposes (Tab. 1) (Ministry of Health, 2009; Ministry of Natural Resources and Environment, 2015; National standards, 2011). Besides, the locations of polluted wells were compared by the authors with the locations of mineral deposits to determine the nature of pollutant emission sources (Figs. 2–3).

2.6 Method of assessing groundwater quality from Groundwater Quality Index results

Based on the study Determination of Groundwater Quality Index (GWQI) by Ahmad (2014), the assessment scale of groundwater quality has five levels: A, B, C, D and E (Tab. 3) (Ahmad, 2014; Chaterjee & Raziuddin, 2002; Mary & William, 1992; Ministry of Health, 2009; Ministry of Natural Resources and Environment, 2015; National standards, 2011).

Analytical methods: Water samplings were done twice at two different sampling periods. Samples were collected in rainy as well as dry seasons of years 2016, 2017 and 2018, using acid washed 0.5 liter polypropylene (PET) bottles to avoid unpredictable changes in characteristic of water according to standard procedures (APHA et al., 1998).

Step 1: Monitoring groundwater quality with Parameters (Tab. 2)

Step 2: Calculation of Water Quality Index (WQI – Tab. 3)

Tab. 3

Water Quality Index (WQI) and status of water quality (Chaterjee & Raziuddin, 2002).

Water Quality Index Level	Water quality status	Grading
0–25	Excellent water quality	A
26–50	Good water quality	B
51–75	Poor water quality	C
76–100	Very poor water quality	D
> 100	Unsuitable for drinking	E

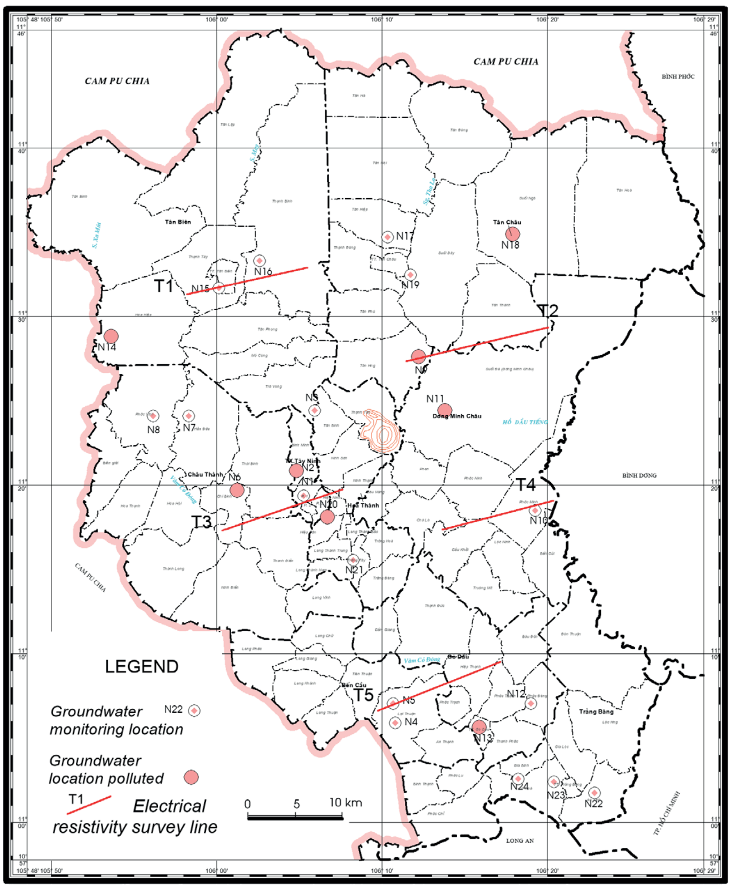


Fig. 3. Wells monitoring groundwater quality and location of polluted wells.

a) Calculation of Sub Index of Quality Rating (qn)

Let there be *n* water quality parameters, where the quality rating or sub index (qn) corresponding to the nth parameters is a number reflecting the relative value of these parameters in the polluted water with respect to its standard permissible value. The value of *qn* is calculated using the following expression.

$$qn = 100\,[Vn - Vio]/[Sn - Vio], \qquad (1)$$

Where qn – Quality rating for the nth water quality parameters,

Vn – Measured value of the nth parameter at a given sampling station,

Sn – Standard permissible value of the nth parameters,

Vio – Ideal value of nth parameter in pure water.

b) Calculation of Quality Rating for pH

For pH the ideal value is 7.0 (for natural water) and a permissible value is 8.5 (for polluted water). Therefore, the quality rating for pH is calculated from the following relation:

$$qpH = 100\ [(VpH - 7.0)/(8.5 - 7.0)], \quad (2)$$

Where VpH = observed value of pH during the study period.

The quality rating qn = 0 means complete absence of pollutants,

Value 0 < qn < 100 implies that the pollutants are within the prescribed standard.

Value qn >100 implies that the pollutants are above the standards.

c) Calculation of Unit Weight (Wn)
Calculation of unit weight (Wn) for various water quality parameters are inversely proportional to the recommended standards value Sn of the corresponding parameters.

$$Wn = K/Sn, \quad (3)$$

Where Wn = Unit weight for the **n**th parameters,

Sn = Standard value for **n**th parameters.

K = Proportional constant, this value considered (1) here, also can be calculate using the following equation:

$$K=1/\Sigma\ (1/Sn). \quad (4)$$

The overall Water Quality Index was calculated by aggregating the quality rating with the unit weight linearly. If Water Quality Index (WQI) is less than 50 such water is slightly polluted and fit for human consumption. When WQI is between (51–80), water is moderately polluted, WQI between (50–100) indicates the excessively polluted and WQI above 100 severely polluted water (Sinha et at., 2004).

$$WQI = \sum_{n=1}^{n} qn\ Wn \Big/ \sum_{n-1}^{n} Wn \quad (5)$$

3. Results

3.1 Aquifers

Research results show that Tay Ninh province has 7 aquifers (6 porous aquifers in Quaternary sediments, 1 in fractured aquifer in Mesozoic-Paleozoic sequences) (Chan et al., 1998; Cuong, 2005; Dung, 1999, 2001; Nghi, 2002; Tay Ninh monitoring resources and environment Center, 2019; Tri, 2000; Tuan et al., 1998):

- Upper Pleistocene porous aquifer (qp^3),
- Middle–Upper Pleistocene porous aquifer (qp^{2-3}),
- Lower Pleistocene porous aquifer (qp^1),
- Middle Pliocene porous aquifer (n_2^2),
- Lower Pliocene porous aquifer (n_2^1),
- Upper Miocene porous aquifer (n_1^3),
- Mesozoic–Paleozoic fractured aquifer (ps-ms).

In which, there are 5 porous aquifers: (qp^{2-3}), (qp^1), (n_2^2), (n_2^1), and (n_1^3) capable of large scale exploitation. Porous aquifer (qp^3) and fractured aquifers (ps-ms) meet the needs of exploiting in retail scale to medium size.

3.2 Position of boreholes

The location of boreholes was determined based on geophysical results, combined with field investigation. Based on the geophysical results we have determined the position and thickness of the aquifers. This result has been verified by boreholes (Tab. 4).

3.3 Monitoring results and groundwater quality

At wells, the registered monitoring parameters represented the water level, pumped quality and targets for the quality of groundwater. The information collected is used to assess the status, change in amount, quality, and other impacts to the groundwater source. The results of groundwater quality analyses in Tay Ninh province are shown in Tab. 5.

Tab. 4
Parameters of porous aquifers.

Aquifers	Roof of the aquifer	Wall of the aquifer	Thickness
Upper Pleistocene porous aquifer (qp^3)	0.0–22.0 m	5.0-46.0 m	4.3–27.0 m
Middle–Upper Pleistocene porous aquifer (qp^{2-3})	0.0–66.5 m	21.0–82.0 m	5.3–48.0 m
Lower Pleistocene porous aquifer (qp^1)	13.0-92.0 m	31.5-121.0 m	13.5–50.0 m
Middle Pliocene porous aquifer (n_2^2)	45.0–153 m	73.0–195.0 m	6.5–91.5 m
Lower Pliocene porous aquifer (n_2^1)	79.5–207.0 m	120.0–243.5 m	17.5–99.5 m
Upper Miocene porous aquifer (n_1^3)	143.5–237.0 m	160.0–302.0 m	16.5–68.0 m

Tab. 5
Analyses results of groundwater samples expressed by the range of obtained values.

TT	pH	Ammonium mg/L	Arsenic mg/L	Chloride mg/L	Chemical Oxygen Demand COD mg/L	Fe mg/L	TDS mg/L	Total hardness $mgCaCO_3/L$	Coliforms bacteria CFU/100 ml	*Escherichia coli* CFU/100ml
N1	4.91–5.78	0.5–1.46	0	22.5–38.1	0–0.71	0–0.04	32.9–183	29.4–59.9	3–240	0–3
N2	4.75–5.83	ND	ND	ND	0–1.04	ND	ND	ND	3–240	ND
N3	4.33–5.69	0–0.79	ND	4.04–21.45	0–0.61	0– 0.26	25.3– 70.3	0.37–8.8	3–43	0–15
N4	5–5.96	0–0.2	0–0.005	5.2–45.5	ND	0–1.26	23.9–69.4	1.39–133	3	0–3
N5	4.2–5.63	ND	ND	ND	0–0.6	ND	ND	ND	2–93	ND
N6	4.81–5.61	0.17– 13.35	0–0.009	10.91–95.23	0–2.02	0–2.9	34.4–329	3.26–51.5	3–460	0–43
N7	5.09–6.01	ND	0–0.003	ND	0–1.3	ND	ND	ND	3–4	ND
N8	4.63–5.81	ND	ND	ND	ND	ND	ND	ND	3–23	ND
N9	5.06–6.53	0–0.3	ND	ND	0–1.11	ND	ND	ND	3–110	ND
N10	4.76–6.46	0–0.3	ND	ND	ND	ND	ND	ND	3–9	ND
N11	4.82–5.89	0–0.1	ND	ND	0–0.6	ND	ND	ND	3–240	ND
N12	5.2–5.88	0–0.04	ND	0–9.17	0–0.66	0–0.02	18.2–50	0–7.82	3–43	0–3
N13	4.59–5.71	0–0.4	ND	ND	0–0.6	ND	ND	ND	0–460	ND
N14	5.01–6.51	ND	ND	ND	0–2.13	ND	ND	ND	0–240	ND
N15	4.15–5.71	ND	ND	ND	0–0.5	ND	ND	ND	3–43	ND
N16	4.15–5.61	ND	ND	ND	ND	ND	ND	ND	3	ND
N17	4.72–6.01	0–0.1	ND	ND	0–0.7	ND	ND	ND	3	ND
N18	4.38–5.51	0.11–6.2	0	0–20.6	0–1.68	0–4.02	30–107.0	7.44–16.8	3	0–3
N19	4.59–5.62	ND	ND	ND	ND	ND	ND	ND	3	ND
N20	4.42–5.55	0.02–5.9	0	5.9–91,0	0–0.59	0–0.08	22–100.9	16.14–25.67	0–460	0–3
N21	4.15–5.28	0–0.14	ND	ND	ND	ND	ND	ND	3–110	ND
N22	5.06–5.73	0–0.2	ND	ND	0–1.0	ND	ND	ND	3	ND
N23	5.04–5.71	0–0.2	ND	ND	0–0.6	ND	ND	ND	3	ND
N24	4.46–5.64	0–0.3	ND	7–76.4	ND	0–0.04	28–198	7.2–27.3	3	0–3

Note: ND (not detected) – the parameter has been not detected during analysis

(i) pH: According to the Ministry of Health standard, the pH value should be from 6.0 to 8.5. All monitoring groundwater samples focused on pH concentration in Tay Ninh province are not responding to this standard. An acidic pH (pH < 6) affects human health, corroding equipment and water containers. It is possible to overcome the pH value by increasing the ventilation level of the groundwater after exploiting, to eliminate CO_2 in the water. When the pH is in accordance with the allowable threshold, it can be used for domestic or drinking water.

(ii) Ammonium: The maximum allowable limit of the Ministry of Health for Ammonium is 0.3 mg/L. Ammonium monitoring results of all groundwater samples throughout Tay Ninh province from 2016 to 2018 show that the areas of Bencau district, Duongminhchau district, Tanbien district, Trangbang district are unpolluted. Tay Ninh City, Chau Thanh district, Godau district, Tan Chau district, Hoatthanh district areas are affected by ammonium from 8.3 % to 58.3 % (rate of water samples for analysis and monitoring). The Tay Ninh city has the highest ammonium contamination.

(iii) Arsenic: The maximum allowable limit of the Ministry of Health for arsenic content is 0.01 mg/L. The results of monitoring of the arsenic content of all groundwater samples of Tay Ninh province from 2016 to 2018 showed that none of the samples was polluted by arsenic.

(iv) Pb: According to Ministry of Health standards, Pb content allowed in groundwater is 0.01 mg/L. The Pb monitoring results of all groundwater samples of Tay Ninh province from 2016 to 2018 showed that none of the samples is polluted by Pb.

(v) Chloride: According to Ministry of Health standards, dangerous chloride content is 300 mg/L. The results of monitoring the chloride of all groundwater samples of Tay Ninh province from 2016 to 2018 supplemented in 2019 showed that only Tan Bien district is unpolluted, other areas of Tay Ninh province were polluted from 33.3 % to 66.6 %. In which, Tay Ninh city has the highest pollution to 66.6 % (12/18 samples).

(vi) Chemical Oxygen Demand (COD): The maximum COD content is 2 mg/L (Standard of Vietnam 02: 2009/MOH). The results of monitoring the COD of all groundwater samples of Tay Ninh province from 2016 to 2018 showed that groundwater samples from Chau Thanh district and Tan Bien district are polluted by 5.5 %, all other areas of Tay Ninh province reached the allowable threshold.

(vii) Fe: The maximum limit by the Ministry of Health allows 0.3 mg/L. The results of monitoring the Fe of all groundwater samples of Tay Ninh province from 2016 to 2018 showed that the groundwater samples from the Chau Thanh district and Tanchau district are polluted from 5.6 % to 22.2 %. The rest of the areas of Tay Ninh province is unpolluted.

(viii) TDS: The maximum limit by the Ministry of Health allows 1,000 mg/L; The results of monitoring the TDS of all groundwater samples of Tay Ninh province from 2016 to 2018 showed that 100 % of groundwater samples from this province met the allowable limit for TDS content.

(ix) Hardness: The maximum limit allowed by the Ministry of Health is 300 mg/L. The hardness monitoring results of all groundwater samples from Tay Ninh province from 2016 to 2018 showed that 100 % of the groundwater samples from this province met the allowable limit for hardness.

(x) Coliforms bacteria: The maximum limit allows by the Ministry of Health is < 3 CFU/100 ml; The results of monitoring the Coliform bacteria of all groundwater samples of Tay Ninh province from 2016 to 2018 showed that Tayninh City, Bencau district, Chau Thanh district, Duongminhchau district, Godau district, Tanbien district, Hoatthanh district are affected by 8.3–55.5 %. In Tay Ninh City, the Coliform pollution is the highest (56 %). Tanchau and Trangbang districts are unpolluted by Coliforms.

(xi) *Escherichia coli*: The maximum limit allowed by the Ministry of Health is < 1 CFU/100 ml; The *E. coli* monitoring results from all groundwater samples of Tay Ninh province from 2016 to 2018 show that Tayninh City, Bencau district, Chau Thanh district, Godau district, Tan Chau district, Hoatthanh district, Trangbang district are affected from 27.7 % to 55.5 %. Tay Ninh city is the most damaged by *E. coli* (56 %). Duongminhchau and Tanbien districts are unpolluted by *Escherichia coli*. In Bencau district, Chau Thanh district, Godau district, Tan Chau district, Hoatthanh district, Trangbang district and Tay Ninh city the *Escherichia coli* and Coliforms are increased due to the characteristics of these districts having livestock farms, but the treatment is not thorough, wastewater overflows, water supply and drainage infrastructure system are not thoroughly synchronized.

The water sources are infected by microbes (*Escherichia coli* and Coliforms bacteria) due to the wastewater seeping into the groundwater resources, by running water from the ground into wells, or by less guaranteed water storage hygiene. When the *E.coli* and Coliform groups of bacteria are identified in the water, it shows that the water source has been affected by human or animal faeces (Ministry of Health, 2009; Ministry of Natural Resources and Environment, 2015; Phu & Phuong, 2019).

3.3 Evaluation of the qroundwater quality with Groundwater Quality Index

Based on monitoring of 24 boreholes and groundwater samples analyses results in the Tay Ninh province from 2016 to 2018 the authors calculated the GWQI values applying formula (5) ((Tabs. 2 and 6). Obtained results allow authors to conclude that the groundwater quality in Ben Cau district and Trang Bang district reaches 100 % of A “Very good” level. In Tayninh city, borehole N2 has a GWQI of 819. In Chauthanh district, borehole N6 has a GWQI of 267. In Duongminhchau district, borehole N9 has a GWQI of 3753. In the Godau district, borehole N13 has a GWQI of 159, in Hoathanh town, borehole N20 has a GWQI of 106. These are areas where good groundwater quality has not been indentified by GWQI.

In general, groundwater quality in research areas changed many times over time and space. Parameters such as pH, ammonium ion, chloride, coliform bacteria, Escherichia coli in some places have exceeded the allowed values. This is a threat to the health of community. Besides, the strong development of industrial zones, the evolution of the mining industry and irresponsible behaviour of people represent threats to the health of community and environment.

3.4 Some causes of affecting groundwater quality in Tay Ninh province

3.4.1 Human causes

Currently, Tay Ninh's population is about 1,171.7 million people (People's Committee of Tay Ninh Province statistical yearbook, 2019). The population increases every year. The land of Tay Ninh province is a constant area (about 4,041 km^2). During development with growing industrial zones, the water demand also increases. Most people's wells, when not in use, are left blank. The people should fill the wells with clay to protect the aquifer. Otherwise the wells will become path for potential contamination from the surface to contaminate the groundwater. Moreover, people pollute the environment by waste. Further contributing to environmental pollution are livestock farms, enterprises of mineral processing, as well as the animal feed processing.

Tab. 6
GWQI values.

Sampling locations	2016	2017	2018	GWQI	Area
N1	41	42	29	37	Tayninh city
N2	2 456	1	2	819	
N3	15	24	7	15	
N4	8	9	65	27	Bencau district
N5	1	1	10	4	
N6	294	230	275	267	Chauthanh district
N7	1	1	29	10	
N8	3	1	1	2	
N9	11 256	1	1	3 753	Duongminhchau district
N10	5	1	2	3	
N11	247	1	1	83	
N12	5	10	11	9	Godau district
N13	475	1	1	159	
N14	1	247	10	86	Tanbien district
N15	1	1	5	2	
N16	1	1	1	1	
N17	2	1	1	1	Tanchau district
N18	105	87	38	76	
N19	1	1	1	1	
N20	142	149	26	106	Hoathanh town
N21	12	113	1	42	
N22	4	1	1	2	Trangbang town
N23	3	1	1	2	
N24	8	7	6	7	

3.4.2 Groundwater quality affected by geological reasons

Most of the area of Tay Ninh province represents a delta environment, being formed of Quaternary sediments.

The geological studies show that Quaternary sediments have many different origins (DGMVN, 2006; Hoa et al., 1992; Tri, 2000; Tuan et al., 1998). The sedimentary facies strongly affecting groundwater quality are represented by lake facies and marshy facies, having a reducing environment, closely related to the peat mines. Favourable places to form sedimentary sequences of lake and marshy facies are areas of subsidence in the past. There are 9 peat mines in Tay Ninh province (Cuong, 2005). These peat mines are distributed in alluvium and marshy sediments along the Vam Co Dong valley and rivers of Chau Thanh and Ben Cau districts. The peat beds have a thickness of about 2.0 m. The peat mines are located there, being monitored in points N2, N6, N9, N11, N13, N14, N18 and N20. To determine relationship of affected wells and geological environment, the authors have overlayed the location of the wells on the map of mineral resources in Tay Ninh province. All polluted wells are located nearby peat mines. So, the diffusion of elements from peat mines to surroundings has affected the groundwater quality of Tay Ninh province (Figs. 3–4).

One of the environmental impacts of peat mining is water pollution, the decrease in pH in peat is caused by humic acids from organic matter rather than by dissolving sulphate.

In addition, in Tay Ninh province, there are mineral deposits such as kaolin clay, brick-tile clay and cement limestone, building stone, limestone clay, pebble, gravel, building sand, laterite and mineral water – hot water (Fig. 4). Exploiting these minerals also affects the water environment of Tay Ninh province. However, in this article we dominantly mention only peat.

The formation of sediment lake and marshy faces is associated with the cycles of transgression and regression. The areas with lake and marshy faces represent favourable places for the accumulation of organic matter. Quaternary sediments in Tay Ninh have been identified by groundwater monitoring wells being up to 87 m thick (Borehole 5-NB, Tan Thanh – Tan Chau). Boreholes located in thick Quaternary sediments will contain also thick lake and marshy faces. We have discovered, analysing the Mineral map of Tay Ninh province, that the boreholes with contaminated groundwater resources are located in areas with marshy deposits. Besides, monitoring points N9, N11, and N18 were polluted due to related deposit points contain Ti and Fe.

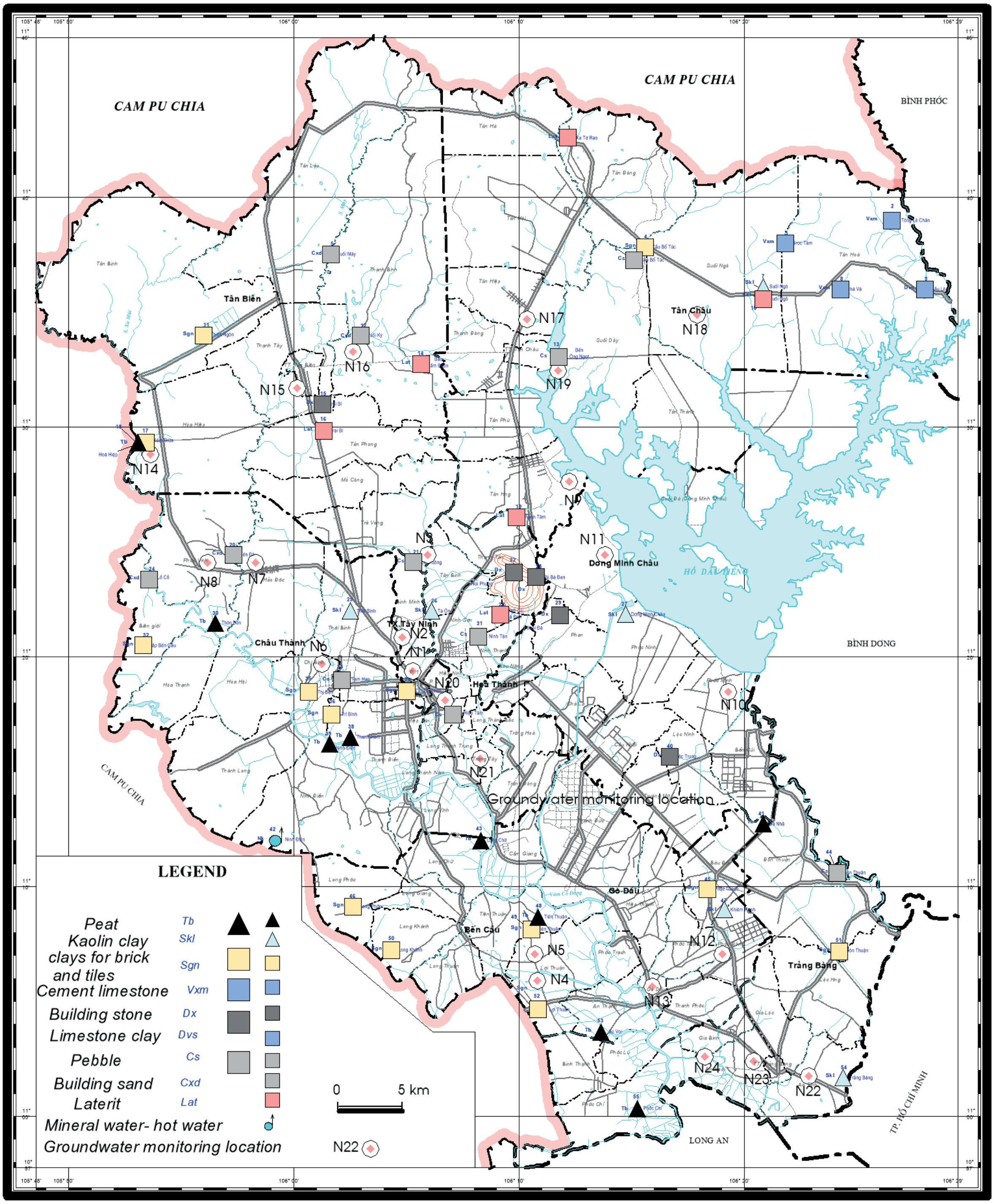


Fig. 4. Map of mineral deposits in Tay Ninh province (DGMVN, 2006).

4 Conclusions

Research results have determined that Tay Ninh province has 7 major aquifer types. Groundwater is mostly super fresh water. Most groundwater has a low pH. In many places, the content of iron, ammonium, coliforms bacteria, Escherichia coli and high chemical oxygen demand (COD) was recorded. In many places, the content of iron, ammonium, permanganate, Coliforms, *E.coli* exceeds the allowable threshold contents. In some places, nitrate content is present in qp3 and qp2-3 aquifers with a high content (> 10 mg/L). The three locations with nitrate increased content are Long Thanh Trung, Long Thanh Nam, and Hoa Thanh towns (the Hoa Thanh district). Based on monitoring results of 24 wells, 8 affected wells were identified, being associated with the peat area and building stone mine, containing high Ti and Fe contents. Towards sustainable development on the water source, Tay Ninh Province needs to do the following tasks:

- To raise the Community Education and the responsibility sense to environmental protection, especially in the Dến Từng village (residential group), as well as the commune (Ward).
- Application of penalties for individuals and organizations for polluting the environment. At the same time, rewarding individuals and organizations behaving well in environmental protection.
- If well system stops working, prevent descending pollution to the aquifers.
- Do not exploit groundwater in aquifer polluted by mineral mines.

In addition, the warming climate and sea level may cause the seawater intrusion to coastal groundwater aquifers and is expected to be more severe in the near future. Tay Ninh needs to take this scenario into account.

Acknowledgments

The research was supported by HUTECH University and Institute of Environmental Technology Promotion and Water Resources Phu My. The remarks and suggestions of reviewer Peter Bajtoš (ŠGÚDŠ, Slovakia) and one anonymous reviewer contributed to improving quality of primary manuscript.

References

APHA, AWWA & WEF, 1998: Standard Methods for the Examination of Water and Wastewater. 20th Ed. *Washington.* DC;

Ahmad, A. B., 2014: Evaluation of Groundwater Quality Index for drinking purpose from some villages around Darbandikhan district, Kurdistan Region, Iraq. *J. Agricult. Veter. Sci.,* 7, I, 9, I34–41. ISSN 2319-2380, p-ISSN 2319-2372. www.iosrjournals.org. DOI: 10.9790/2380-07913441.

Chan, N. Đ. et al., 1998: Geological investigation Tay Ninh City – Thudaumot, scale 1 : 25.000. Archived in Tay Ninh province.

Chaterjee, C. & Aziuddin, M., 2002: Determination of water quality index (WQI) of a degraded river in Asanol Industrial area, Raniganj, Burdwan, West Bengal. *Nat. Environ. pollut. Technol., 1, 2, 181–189.*

DGMVN (Department of Geology and Minerals of Vietnam), 2006: Mineral Resources of Tay Ninh Province.

Department of Environmental Management – Ministry of Health, 2016: Guide Water treatment family by simple measures.

Dinh, B. T., 1992: Mapping Report on hydrogeology – Southern Engineering Geology, scale 1 : Report on200.000. Archived in Department of Geology and Minerals of Vietnam.

Dung, N. Q., 1999: Exploration of natural mineral water in Ninh Dien – Chau Thanh area. Final report. Archived in Tay Ninh province.

Dung, N. Q., 2001: Groundwater exploration in Go Dau – Tay Ninh area. Final report. Archived in Tay Ninh province.

Dung, N. Q., 2005: Report exploration mining groundwater in Moc Bai – Ben Cau area. Final report. Archived in Tay Ninh province.

Exploration mining of groudwater in Tan Hoa, Tan Chau for construction of Tay Ninh Cement Factory, 2005: Final report. Archived in Tay Ninh province.

Hoa, N. N. et al., 1992: Geological map of the Southern Delta, scale 1 : 200.000. Archived in Department of Geology and Minerals of Vietnam.

Hung, D. T., 1999: Investigation status of reserves, groundwater quality, and use planning up to 2010 in Tay Ninh province. Archived in Department of Geology and Minerals of Vietnam.

Institute of Environmental Technology Promotion and Water Resources Phu My, 2019: Groundwater Research Report and Sustainable Development orientation for social-economic development in Tay Ninh province.

Loke, M. H., 2015: Tutorial for: 2-D and 3-D electrical imaging surveys. Archived in Tay Ninh province.

Mary, P. A. & William, W. W., 1992: Applied groundwater modeling. *New York, Acad. Press.*

Ministry of Health, 2009: National Technical Regulations about the quality of drinking water (Standard of Vietnam 02: 2009/MOH).

Ministry of Natural Resources and Environment, 2015: National Technical Regulations about groundwater quality (Standard of Vietnam 09: 2015/Monre).

National standards, Standard of Vietnam 6663-1: 2011, Sampling – Part 1: Guidance on the design of sampling programmes and sampling techniques, 2011.

Nghi, V. V., 2002: Exploration mining underground water industrial Linh Trung 3 – Trang Bang area. Archived in Tay Ninh province.

People's Committee of Tay Ninh Province, 2017: Report No 375/Report-PC date 03/12/2018 on The implementation Development socioeconomic plan in 2018 and Development socioeconomic plan in 2019.

People's Committee of Tay Ninh Province, 2018: Report Assembly series Hydrogeological map (scale 1/500) and IT applications in groundwater management for zoning exploitation of resources in Tay Ninh province.

People's Committee of Tay Ninh Province, 2019: Statistical yearbook. *Statistic. Publ. House*.

Phu, H. & Phuong, H. T. T., 2019: Applied research of groundwater quality index (GWQI) to assess suitability for domestic use purposes and proposing management and treatment measures in Tay Ninh province. Archived in Tay Ninh province.

Standard of Vietnam 5944. Standard groundwater quality, Hanoi, 1995.

Tay Ninh Environment and Natural Resources Department. Tay Ninh environmental quality monitoring plan. Report, 2018.

Tay Ninh monitoring resources and environment Center. Results from the report on groundwater quality monitoring of Tay Ninh Environmental Monitoring Center in 2016, 2017, 2018, 2019.

Tri, V. K., 2000: Investigative report on potential, reserves, and quality of surface water in Tay Ninh. Archived in Tay Ninh province.

Trinh, L., 2008: Research water quality partition according to groundwater quality index (WQI) and assess the ability to use water resources, river canal in Hochiminh area. Archived in Tay Ninh province.

Tuan, A. T. et al., 1998: Report on hydrogeological mapping – engineering geological map of Tay Ninh. Archived in Tay Ninh province.

UNEP, 2003: Groundwater and its Susceptibitity to Degradation: A global assessment of the problem and options for management. https://nora.nerc.ac.uk/id/eprint/19395/

Vietnam Environment Administration, 2010: Calculation of water quality index method (WQI).

Vietnam Environment Administration, 2011: No: 879/ Decision--VNA, notebook guide to calculating water quality index.

Vzťah kvality podzemnej vody a ložísk rašeliny na príklade monitorovacieho výskumu v provincii Tay Ninh, Vietnam

Kvalita podzemnej vody v provincii Tay Ninh vo Vietname (obr. 1) sa skúmala v rokoch 2016 až 2019 monitorovaním 24 lokalít (obr. 3 a 4, tab. 1 a 5).

Lokalizovanie miest pozorovania sa zrealizovalo geofyzikálnym profilovaním aplikáciou odporových meraní, na základe ktorých boli následne vyhĺbené monitorovacie vrty (obr. 2 a 2A). Odobraté vzorky na miestach monitorovania sa testovali na nasledujúce parametre: pH, obsah amónnych iónov, arzénu, chloridov, COD, Fe a TDS, celková tvrdosť, prítomnosť koliformných baktérií a *Escherichia coli*.

Po spracovaní výsledkov viacročného monitorovania bola kvalita podzemnej vody na jednotlivých lokalitách vyhodnotená pomocou komplexného klasifikačného indexu (tab. 6). Bolo identifikovaných 8 lokalít s veľmi zlou kvalitou podzemnej vody, predovšetkým pre nízke pH a vysoký obsah železa a amónnych iónov. Zvyšných 16 lokalít si zachovávalo dobrú kvalitu vody. Z porovnania pozície lokalít s nepriaznivou kvalitou podzemnej vody a ložísk rašeliny vyplynulo, že zhoršenú kvalitu podzemnej vody spôsobujú popri ľudskej činnosti hlavne tieto ložiská. Boli navrhnuté zodpovedajúce nápravné opatrenia.

Doručené / Received: 29. 11. 2021
Prijaté na publikovanie / Accepted: 21. 6. 2022