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**Sustainable Management of Environment and  
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# Distribution of saline and freshwater in groundwater in Thai Binh province and solution for reasonable exploitation

*Hiện trạng phân bố mặn – nhạt nước dưới đất tỉnh Thái Bình và đề xuất giải pháp khai thác hợp lý*

Research article

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Thai Binh is a coastal province of Red River Delta in Vietnam, having administrative boundaries at the river systems and coastlines that cause groundwater quality varies complicatedly. Today in Thai Binh province, the groundwater in Holocene and Pleistocene aquifers is exploited for domestic use. But, beside the quality of groundwater in this region is not uniform, it is interspersed between salt water and fresh water zones in Holocene and Pleistocene aquifers. Nowadays, under the force of groundwater exploitation activity for domestic purposes, agricultural activities, the impact of climate change and sea level rise issues, the quality of distribution of groundwater here change. According to the recent research results, groundwater quality and distribution of salt water - fresh water there have many changes compared with the research results of the Northern Division for Water resources Planning and Investigation in the year 1996. For the the Holocene aquifer (qh), distribution area of salt water zone has been narrowed. Besides, saline cleaning process occurred in some coastal areas in Tien Hai, Thai Thuy and a part of Quynh Phu district. For the Pleistocene aquifer (qp), compared with research result in 1996, the boundaries between saline and fresh water at the present time is not change so much. By assessing the status of the distribution of saline and fresh water zones in groundwater in Thai Binh and the movement of this boundary, author's research results will be the basis that helps the managers give out reasonable exploiting and sustainable using methods for these natural resources.

Thái Bình là một tỉnh ven biển thuộc vùng châu thổ sông Hồng của Việt Nam, được bao bọc bởi hệ thống sông biển khép kín làm cho chất lượng nước ngầm biến đổi rất phức tạp. Hiện nay, tại Thái Bình có 2 tầng chứa nước chính phục vụ ăn uống sinh hoạt là tầng chứa nước Holocen và tầng chứa nước Pleistocen. Tuy nhiên, chất lượng nước ngầm ở các tầng chứa nước này không đồng đều, có sự phân bố xen kẽ giữa các khoảng nước mặn và nước nhạt. Hiện nay, dưới tác động của hoạt động dân sinh, sản xuất nông nghiệp, khai thác nước phục vụ sinh hoạt cùng ảnh hưởng của biến đổi khí hậu và sự dâng cao của mực nước biển đã làm thay đổi chất lượng và quy mô phân bố nước ngầm khu vực. Theo những kết quả nghiên cứu mới nhất của tác giả cho thấy diện tích phân bố của các vùng nước mặn - nước nhạt của các tầng chứa nước trên địa bàn tỉnh đã có nhiều thay đổi so với kết quả nghiên cứu trước đây của Liên đoàn Địa chất thủy văn – Địa chất công trình miền Bắc năm 1996. Với tầng chứa nước Holocen, diện tích phân bố các khoảng nước mặn bị co hẹp và đang có sự nhạt hóa tại một số khu vực ven biển thuộc Huyện Tiên Hải, Thái Thụy và một phần thuộc huyện Quỳnh Phụ. Trong tầng chứa nước Pleistocen (qp), so với kết quả nghiên cứu năm 1996, ranh giới mặn – nhạt tại thời điểm hiện tại đã có sự thay đổi nhưng không lớn. Kết quả nghiên cứu này là cơ sở giúp các nhà quản lý đề xuất giải pháp, phân vùng khai thác và sử dụng hợp lý nguồn tài nguyên thiên nhiên này đặc biệt trước tình trạng khan hiếm nước như hiện nay trên địa bàn tỉnh Thái Bình.

**Keywords:** aquifer, groundwater, Holocen, instrution, Pleistocence, rainfall

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## 1. Introduction

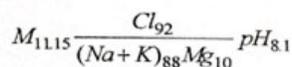
Thai Binh is one of coastal provinces in the Red River delta having administrative boundaries at the river systems and coastlines. Research results of previous scientists showed that hydrogeology characteristics of this area are very complex.

The studying area have two main aquifers that are Holocen (qh<sub>1</sub> - qh<sub>2</sub>) and Pleistocen (qp) aquifers. These aquifers were separated by clay layer of Hai Hung and Vinh Phuc formation. The distribution of aquifers and aquitards is shown in Figure 1.

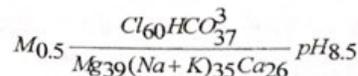
### 1.1 Upper Holocene unconfined aquifer (qh<sub>2</sub>)

This is the uppermost aquifer, which is distributed throughout the studying area. It is mainly composed of fine sand and occasionally with silty sand. The thickness increases from the North - North West to the South - South East, with maximum is 25 m. Groundwater level is from 1 to 2 m depending on the seasons. Transmissibility coefficient is 1.8 m<sup>2</sup>/day, hydraulic conductivity is 1.49 m/day and storage coefficient is 0.18.

The chemical composition of qh<sub>2</sub> aquifer in saline areas has Na - Ka - Cl type and is shown in the following formula:



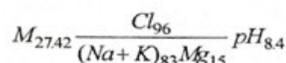
The chemical composition of qh<sub>2</sub> aquifer in fresh areas has Mg - Na - Ka - Cl type and is shown in the following formula:



### 1.2 Weakly confined lower Holocene aquifer (qh<sub>1</sub>)

This aquifer underlies the upper aquifer qh<sub>2</sub> and also is distributed throughout studying area. It is mainly composed of grey quartz mixed with plant humus, and mica. The average thickness is 14.2 m, and hydraulic conductivity is from 0.61 to 1.0 m/day.

The chemical composition of qh<sub>1</sub> aquifer in fresh areas has Na - Ka - Mg - Cl type and is shown in the following formula:



The previous research results indicated that the groundwater quality of Holocen aquifer is uneven and complicated variability. The main recharge sources for this aquifer were from rainy water and surface water. Water table depends on the meteorological condition. The result of pumping test in some boreholes is from 40 ÷ 60 m<sup>3</sup>/day. The groundwater quality is usually contaminated by microorganisms. Although it is distributed at shallow depth, therefore easy to exploit, it cannot be used productively.

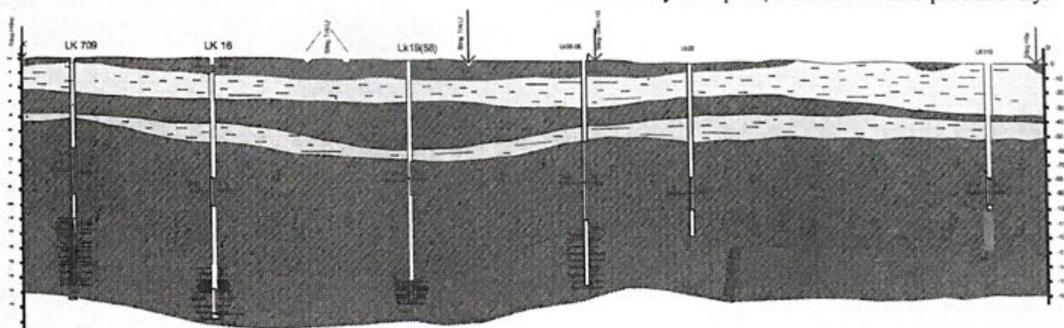


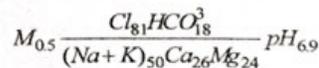
Figure 1. Hydrogeology crosssection in Thai Binh province

### 1.3 Confined interstitial Pleistocene aquifer (qp)

This aquifer is distributed throughout the study area and only opened on surface at Quynh Phu district. Its component is mainly composed of fine to medium coarse sand, some gravel and clay. The thickness is from 36 to 61 m depending on place, average thickness is 57 m. Transmissibility coefficient is 1.8 m<sup>2</sup>/day and storage coefficient is 0.18. We can divide this aquifer into two areas based on total dissolve solids (TDS) value, one part in the North with TDS value lower than 1.0 g/l and another in the South with TDS value higher than 1.0 g/l.

The aquifer area with TDS lower than 1 g/l is distributed in the northern part of the province which under the administrative scope of the Hung Ha, Dong Hung, Quynh Phu districts and a part of Thai Thuy district. TDS values were from 0.3 to 1.0 g/l.

The chemical composition in fresh areas has Na - K - Ca - Mg - Cl - HCO<sub>3</sub> type and is shown in the following formula:



This is the main aquifer to be abstracted for centralised domestic water supply for the residents of this area. Re-

sult of pumping test was about 11.3 l/day, transmissibility coefficient was 1.5 m<sup>2</sup>/day and hydraulic conductivity was 22 m/day.

The aquifer area with TDS higher than 1 g/l is distributed in the southern part of the province which under the administrative scope of the Kien Xuong, Tien Hai, Vu Thu districts and a part of Thai Thuy district. TDS value in some places was up to 29 g/l.

The chemical composition is Na -Ka - Mg - Ca- Cl type and is shown in the following formula:

$$M_{29} \frac{Cl_{92}}{(Na+K)_{70} Mg_{18} Ca_{11}} pH_{8.4}$$

At the present, the quality and storage of groundwater in Thai Binh province change so much under the impacts of industrialization processes, groundwater exploitation activity for economic purposes, climate change, and sea level rise. To manage and protect this resources, we need to have an overview and the updated data of the distribution, the quality and storage of groundwater. The authors have done several tasks to solve this question.

## 2. Subjects and methodology

### 2.1. Subject

The study focused mainly on Holocen and Pleistocen aquifers, re-definition of the distribution areas of salt water and fresh water, and detemination of hydrogeology parameters of aquifers.

## 2.2. Methodology

To research and determine the distribution of saline and fresh water areas in Holocene and Pleistocene aquifers in Thai Binh province, the combinatorial hydrogeological methods including outdoor and indoor were used as follow:

- Survey task;
- Geophysical method;
- Pumping test;
- Water sample analysis in laboratory;
- Rapid measurement method;
- Hydrogeology test;
- Establishment of the map.

Purposes of these tasks are to detemine hydraulic relationship between aquifers and surface water, flow direction, physical and chemical characteristics of groundwater, and hydrogeology and geology characteristics of the aquifers.

In this research, more than 90 observation points over the studying area were arranged. Our observed results were combined with other observation results of National Center for Water Resources Planning and Investigation.

To determine the origin formation and the movement of groundwater, especially the change of the distribution of saline water zones, the following parameters were measured: TDS, Ca<sup>2+</sup>, Mg<sup>2+</sup>, K<sup>+</sup>, Na<sup>+</sup>, HCO<sub>3</sub><sup>-</sup> and Cl<sup>-</sup>. The new boundary distribution of saline and fresh groundwater areas in Thai Binh province was built and compared with the previous research in 1996.

**Table 1: Chemical component of groundwater in Thai Binh province**

No	Sample	District, aquifer	pH	TDS (mg/l)	Anion, mg/l					Cation, mg/l		
					Ca <sup>2+</sup>	Mg <sup>2+</sup>	K <sup>+</sup>	Na <sup>+</sup>	Fe <sup>3+</sup>	HCO <sub>3</sub> <sup>-</sup>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>
1	NN1	Vu Thu, qh <sub>2</sub>	7.4	562	58.12	40.13	49.8	110.0	3.5	439.3	113.4	36.1
2	M5	Vu Thu, qp	7.1	1,250	90.16	133.8	39.4	915.0	3.7	299.0	1,826	12.0
3	M4	Tien Hai, qh <sub>2</sub>	4.2	350	40.00	53.00	10.7	260.0	4.10	152.0	85.00	3.90
4	NN13	Tien Hai, qp	8.5	5,820	87.21	138.2	42.1	1,215	4.92	609.2	4,077	2.82
5	NN18	Thai Thuy, qh <sub>2</sub>	7.9	2,860	79.16	106.4	36.00	895.0	4.89	598.0	1,569	2.40
6	M6	Thai Thuy, qp	7.2	120	45.0	26.1	9.15	435.0	0.06	204.0	403.0	42.0
7	M10	Dong Hung, qh <sub>2</sub>	6.70	545	29.00	75.00	4.00	91.63	1.40	179.0	128.0	9.70
8	NN28	Dong Hung, qp	7.5	1,729	58.12	102.1	35.5	508.0	5.93	927.5	567.2	164.5
9	NN32	Hung Ha, qh <sub>2</sub>	6.9	854.0	61.12	54.7	5.75	165.0	19.9	170.9	460.9	2.40
10	M7	Hung Ha, qp	7.0	742	23.0	96.0	3.9	76.1	2.9	328.0	162	6.00
11	M2	Quynh Phu, qh <sub>2</sub>	6.7	545	29.0	75.0	4.0	91.63	1.40	179.0	128.0	9.70
12	M1	Quynh Phu, qp	6.76	400	23.0	12.0	3.76	63.0	6.40	272.0	11	5.20
13	NN2	Kien Xuong, qh <sub>2</sub>	7.4	980	32.5	32.0	16.94	58.56	1.20	586.0	1,072	11.3
14	NN3	Kien Xuong, qp	7.3	1,250	80.16	156.6	66.0	1.430	3.90	1,062	2,198	18.00
15	NN4	TP Thai Binh, qh <sub>2</sub>	8.0	843.0	56.11	57.15	98.5	192.5	5.75	524.77	239.3	2.4
16	NN5	TP Thai Binh, qp	7.75	282.0	27.50	24.27	0.73	34.20	5.12	158.7	113.4	2.4

### 3. Results and discussion

The collected data of hydrogeology characteristics, the exploitation status of groundwater in 2013 and 2014 are shown in Table 1. The distribution of saline and freshwater areas in Holocene and Pleistocene aquifers was newly drawn (Figure 3).



Figure 2. Monitoring the quality of groundwater in Thai Binh province

#### 3.1 Holocen aquifer (qh<sub>2</sub>)

We can see that the shape and the distribution of saline and freshwater areas had many changes.

The areas of freshwater zones with TDS lower than 1g/l have been expanding at the region of Dong Hung and Quynh Phu districts. The areas of saline water zones were narrowed and combined together at the regions of Vu Thu, Kien Xuong and Tien Hai districts.



Figure 3. Distribution map of saline and fresh water areas in Holocen aquifer

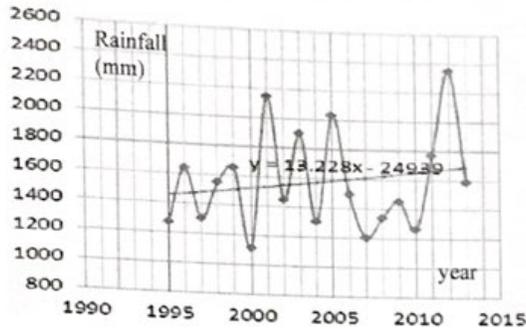


Figure 4. Rainfall in Thai Binh, 1995 – 2013

The main causes of these changes were that the Holocene aquifer was not the main aquifer used to extract groundwater for domestic purpose. This aquifer had directly hydraulic relationship with surface water resources. And the rainfall have been increasing during past years (Figure 4). That means there were recharged water resources and the factors of saline cleaning process for this aquifer.

#### 3.2 Pleistocene aquifer (qp)

The distribution of saline and freshwater zones in Pleistocene aquifer was not changed so much. There was only a small change in some places of Dong Hung and Thai Thuy districts (Figure 5).

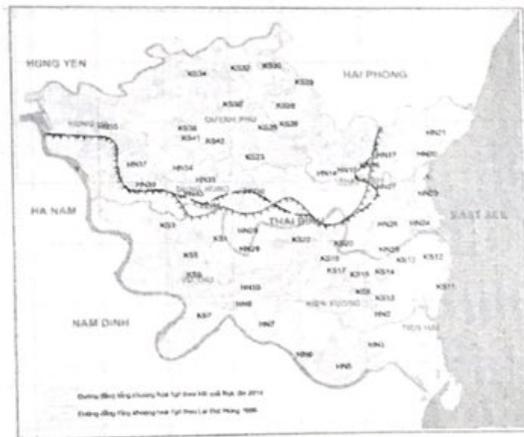


Figure 5. Distribution map of saline and fresh water areas in Pleistocene aquifer

According to observation and previous data, the flow direction of groundwater in this aquifer was from the North, West North to the South. Groundwater table in this aquifer was drawn down during the past years. Figure 6 shows the level of groundwater table at one of the National observation wells.

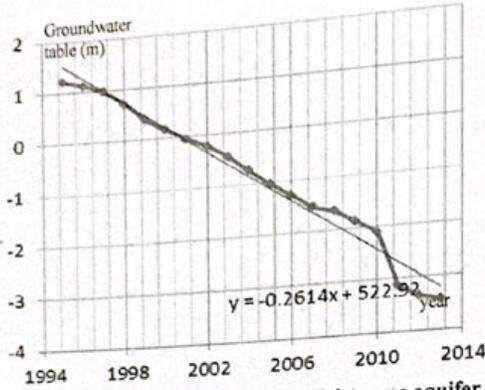


Figure 6. Level of groundwater in Pleistocene aquifer at National observation well 165a

Table 2. The percentage of the population using clean groundwater

No	District	Population	Number people use clean water groundwater				Total	%
			Private well	Dug well	Water supply system			
1	Thai Binh	66.937	13.250	10.145	30.000	53.395	80	
2	Kien Xuong	237.410	38.460	37.895	8.001	84.356	35	
3	Thai Thuy	259.629	53.975	47.675	9.996	111.646	43	
4	Dong Hung	252.220	76.000	34.015	6.003	116.018	46	
5	Hung Ha	247.349	72.150	40.315	4.007	116.472	47	
6	Quynh Phu	240.013	74.200	48.655	6.240	129.095	54	
7	Tien Hai	206.874	27.040	34.930	5.172	67.142	32	
8	Vu Thu	228.726	36.850	43.960	4.003	84.813	37	

To manage and exploit groundwater sustainably, some proposals and solutions were given as follows: at some areas that the Pleistocene aquifer has TDS value higher than 1g/l such as in Tien Hai, Kien Xuong, Vu Thu districts and a part of Thai Thuy district, we can extract groundwater in the Holocene aquifer. Reducing the number of private wells and replacing them by water plants to protect the aquifer from pollution sources and to control exploitation activities. We can build exploitation well systems using Bank infiltration technology developed by Nagaoka - Japan to exploit groundwater in shallow aquifers with medium thickness in Holocene sediment.

In some areas as in Dong Hung, Quynh Phu, and Hung Ha districts where groundwater was exploited in the Pleistocene aquifer, we need to relocate reasonably the exploiting wells far away from the saline boundary to limit the movement of this boundary by exploitation process and reduce the number of individual wells to protect aquifer.

#### 4. Conclusion

The new distribution of saline and fresh groundwater zones in Pleistocene and Holocene aquifers was found. In Holocene aquifer, the freshwater areas have been expanding through the saline cleaning process. Groundwater has close relationship with surface water sources and rainy water. We can exploit groundwater at the depth from 20 to 30 m by Bank infiltration technology at coastal districts such as Tien Hai and Thai Thuy.

The cause making the changes in this aquifer is the exploitation process which has been making groundwater level of this aquifer go down. However, the exploitation yield of groundwater in this area was not so high, need 300,000 m<sup>3</sup>/day. According to statistic data of Thai Binh Department of natural resources and environment, the whole province had 216,926 wells funded by UNICEF with capacity about 200,000 m<sup>3</sup>/day, 100 industrial exploitation wells with exploitation capacity about 20,000 m<sup>3</sup>/day, and 6 groundwater treatment plants (Table 2).

The new distribution map of saline and freshwater zones in Holocen and Pleistocen aquifer will help managers give out reasonable exploiting and sustainable using methods for these natural resources.

In Pleistocene aquifer, the new distribution of saline and freshwater zones did not change so much in comparison with research result of previous scientists in the year 1996. We can exploit groundwater at the depth from 50 to 150 m in Hung Ha, Dong Hung, Quynh Phu districts and a part of Thai Thuy district but well fields need to be built far from the saline boundaries.

Finally, to manage and exploit groundwater safely and stably have to reduce the number of private boreholes and replace by water plants.

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