Nguyen Quoc Long - Pham Thi Lan
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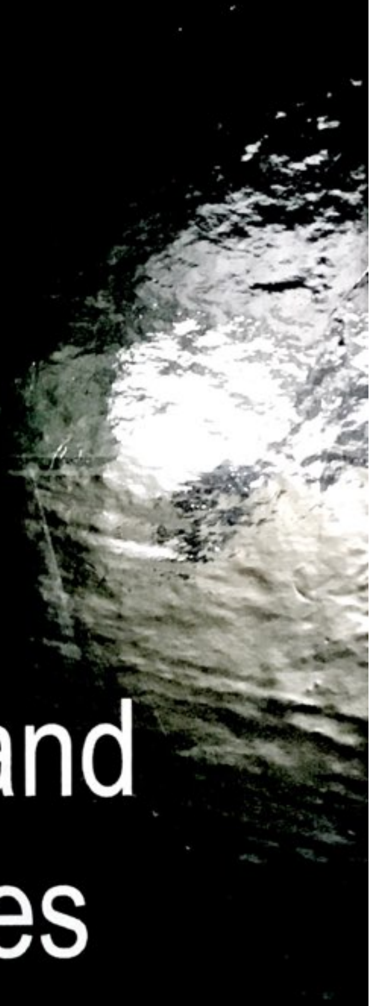

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Study the impact of climate change and sea level rise on groundwater resources in Thai Binh province, Vietnam

Tran Thi Thanh Thuy[a]*, Do Van Binh[a]

[a]Hanoi University of Mining and Geology, Hanoi, Vietnam
*Corresponding author: tranthithanhthuy@humg.edu.vn

ABSTRACT: Thai Binh is a coastal plain province in the North of Vietnam. Groundwater resources in the region are affected by climate change and rising sea levels. Due to the impact of climate change, groundwater resources are salinized, thus negatively impacting livelihoods and production. Studying the impacts of climate change and sea level rise on water resources plays an important and meaningful role in the rational exploitation and use of precious resources for sustainable development. Using numerical model method (Modflow), the author has shown the effects of climate change and sea level rise on both Holocene (qh) and Pleistocene (qp) aquifers in Thai Binh province. Climate change has altered the amount of infiltration to both aquifers in Quaternary sediments. Sea level rise affects salinity intrusion for Holocene aquifer within 1.5 km from the sea inland. Calculated results will help water resource managers to orientate, exploit, and sustainably protect the aquifers.

KEY WORDS: Thai Binh, climate change, saline intrusion, groundwater resources

1. INTRODUCTION

Thai Binh is a coastal province in the Red River delta, so its underground water resources are influenced by many factors. Aquifers have complex hydro-geochemical characteristics. Salt water and fresh water are mixed with no laws, so the impact of climate change and sea level rise is more complex. Climate change increases the frequency of storms, droughts, sea level rise, deep sea intrusion, the reduction of agricultural land, the salinization of water sources. This has made it very difficult to exploit and use underground water resources sustainably.

Climate change and sea level rise are leading causes of saltwater intrusion in aquifers. Shortages of water, scarcity of fresh water or salinity of water source are becoming a pressing issue in Thai Binh. Therefore, "Researching and forecasting the impact of climate change and sea level rise on the groundwater in Thai Binh province" is a very necessary in both scientific and practical matter. The paper discusses the impacts of climate change and sea level rise on the changes in groundwater reserves and groundwater quality in the study area and proposes plans to respond to saline intrusion in water layers in the study area.

2. PURPOSES, TASK AND RESEARCH METHODS

Purpose: a/ To explore and evaluate the relationship between groundwater and climate, sea water; b/ To assess the impact of climate change, sea level rise on quality changes and groundwater reserves in the study area; and c/ To forecast the impact of climate change and sea level rise on groundwater.

Tasks

- Study the geological structure, hydrological geology to clarify the formation of sediments, lithological composition, distribution of aquifers and division of hydrological, geological structure of the survey area;

- Study the formation process of major aquifers in the study area and distribution of their salt and fresh water as a basis for studying the effects of sea level rise and change in precipitation, evapotranspiration to the process of shifting the salt and fresh water boundaries of underground water in the study area;

- Establish the relationship between groundwater with rainwater and sea water to determine the relationship between river water and sea water with groundwater;

- Forecast the impact of climate change and sea level rise on groundwater in Thai Binh province using Seawat model combined with Modflow and MT3DMS packages in Visual Modflow software.

Research methods: To solve the objectives, the authors used the following general research methods:

- Field survey method: implementation monitoring trials to evaluate the quality of groundwater environment, distribution of TDS across the province to correct the salt-fresh water boundary as the basis for forecasting the movement of this boundary under the impact of climate change and sea level rise.

- Hydrodynamic method: monitoring the groundwater level, river water, and sea level over time in the study area to assess the relationship each other. - Modeling method: using the model of GMS, Modflows, SEAWAT... to setup a flow model of Holocene and Pleistocene aquifers. Forecasting changes in salt-fresh water boundaries due to the impact of climate change and sea level rise.

3. RESULT AND DISCUSSION

The study documents were carried out in over 100 boreholes in the study area. These features is the basis for assessing the relationship between groundwater and the factors of climate, hydrological and climate change. Be seen as follows:

3.1. Holocene aquifer (qh)

The Holocene aquifer is distributed and exposed in most areas of the province. The thickness, as well as the permeability of the aquifers, have affected the complementary roles of rain, rivers, and seas, changing the salt-fresh water boundary of groundwater (Le Thi Thanh Tam, 2011), (Nguyen Van Hoang, 2012). To assess the relationship of qh aquifer with climate and hydrological factors, the authors have analyzed concentrations of Na + and Cl-. The author has developed a map of the distribution of the salt - fresh water boundary of the qh aquifer in Thai Binh province (e 1). In it, the fresh, brackish water and salt water areas are intertwined. Where the permeability is low, the groundwater flow rate is less related to river water. The chemical type of water in seawater is usually chloride - sodium potassium.

Fig 1. Salt - fresh water boundary of Holocene aquifer in 1996 and 2014

Investigation showed that the distribution area of salt water zone in Holocene aquifer had been narrowed about 180 square kilometers compared to 1996.

3.2. Pleistocene aquifer

- Na^+ content ranges from 5.0 to 2606 mg/l, averagely 200 mg/l. The area with Na^+ values greater than 1000 mg/l is in Dong Quy commune, Tien Hai district. Water in the borehole near the sea is mostly brackish, saline and iron-contaminated.

- Cl^- content varies from 12.0 ÷ 2198 mg/l. The distribution of Cl^- concentrations is compatible with the mineralization distribution in salty, fresh water areas.

- The value of TDS varies widely from 0.12 to 5.58 g/l. Based on the value of TDS the authors have built the map of salt - fresh water distribution as shown in Fig 2. The fresh water area (TDS <1 g/l) is distributed in the northern part creating a continuous stretch from Hung Ha, Dong Hung and Quynh Phu districts and part of Thai Thuy district. Brackish to the saline area (TDS > 1 g/l) is distributed in the south of the province including Kien Xuong, Tien Hai, Vu Thu and part of Thai Thuy district.

Compared with the results of the study in 1996, the salt-fresh water boundary of qp aquifer has been shifted, but not much. Some saline areas are narrowed such as in Dong Hung district, Thai Thuy district.

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Fig 2. Salt - fresh water boundary of Pleistocene aquifer in 1996 and 2014

3.3. The impact of climate on groundwater

Research results show that rainwater effects water of qh aquifer. The difference in water level between rainy season and dry season is about 0.2 ÷ 0.5 m. It means that rainfall has contributed significantly to the formation of the water reservoir of Holocene aquifer. Fig 3 is shown the change of rainfall and the groundwater level over time.

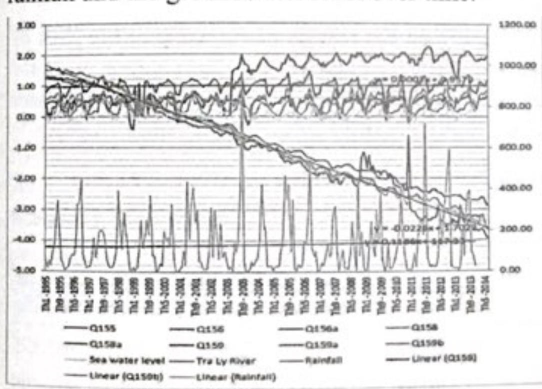

Fig 3. Graph indicating the variation of rainfall and groundwater level rise at boreholes monitored over time

The Holocene aquifer is related of rainfall so that the water level increases. The author has calculated that the amount of rainwater added to the qh aquifer in the rainy season is 25 ÷ 27% of rainfall and the total amount of water replenished is about 345,460 m^3/day (Chyan – Deng Jan et al., 2007). This edition has been increased since 1996, so the area of the fresh water is widened.

The q_p aquifer is also influenced by rainwater but not significantly. The Pleistocene aquifer level decreases over time. For the q_p aquifer, the amount of water permeated from q_h aquifer to qp aquifer is very small, from $2.0.10^{-7} \div 6.0.10^{-7}$ m/yr or approximate 1,000 m^3/day.

3.4. Impact of river water and sea water on groundwater

Research results at QT1.1, Q155, QT1.5, QT1.10 and QT1.12 indicate that water level of q_h aquifer is correlated positively with river and sea water levels (Fig 4).

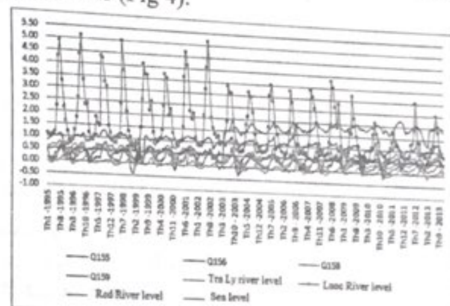

Fig 4. The graph showing the relationship between the water standards of the Holocene aquifer and river and sea water

Along the inland direction (1.5 ÷ 2.0 km), q_h aquifer is related to sea water. From 3.0 km deep into the land, groundwater and sea water fluctuate not synchronized with each other, ie groundwater is not affected by the sea level fluctuations.

To assess the impact of sea water on qh aquifer, the author has established the relationship between sea level and groundwater level. Develop a relationship with them to determine the amount of replenishment of sea water for this aquifer (Fig 5). Relational expressions are:

$$y = 0,3254\,x + 0,00946 \quad (1)$$

Based on that relationship, we use (1) to determine that when the sea level increased by 10%, the groundwater level increased to 3.5 ÷ 4%.

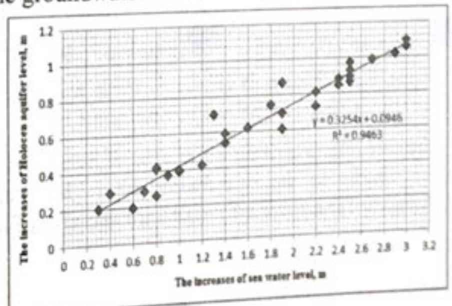

Fig 5. Graphs showing the relationship between sea level and water level of qh aquifer

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The groundwater in the qp aquifer at a distance of 1.5 to 2.0 km from the sea to the inland also has a hydraulic relationship with sea water. However, the level of relationship is small and slower.

3.5. Forecasting the impact of climate change and sea level rise on groundwater

Sea level rise on aquifers are predicted the impact of climate change by using the Visual Modflow and Seawat. The modeling approach was validated by solving Henry's steady-state solution. The model describes the groundwater flow system with the river and coastal boundaries, topographic condition, hydrogeology parameters (hydraulic conductivity, specific yield, groundwater level, and so on), exploited condition and precipitation, evaporation (Nguyen Tuan Anh and Pham Tat Thang, 2014), (Nguyen Van Lam, 2015). Later simulations transient effects of sea-level rise on the saltwater wedge in groundwater with the vertical sea - land interface (Do Van Binh, 2014). The change in salinity - freshmen boundaries over time in Holocene aquifer is shown in Fig 6.

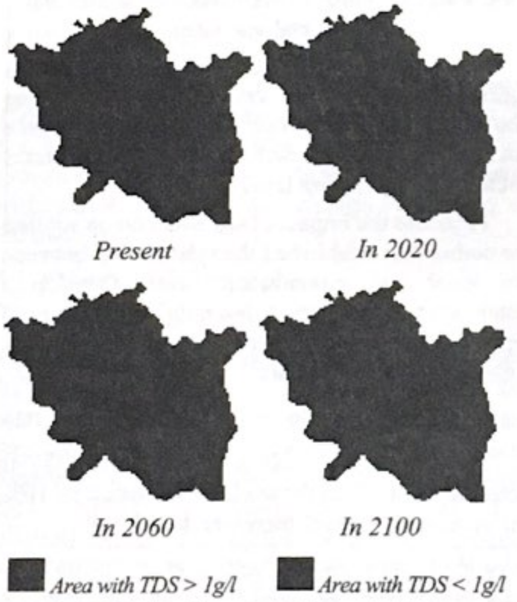

Fig 6. Distribution of salinity – fresh water boundary of qh aquifer over time

The salt - fresh ground water area of Pleistocene aquifer tends to be narrowed down but not significantly. The forecast results are shown in Fig 7.

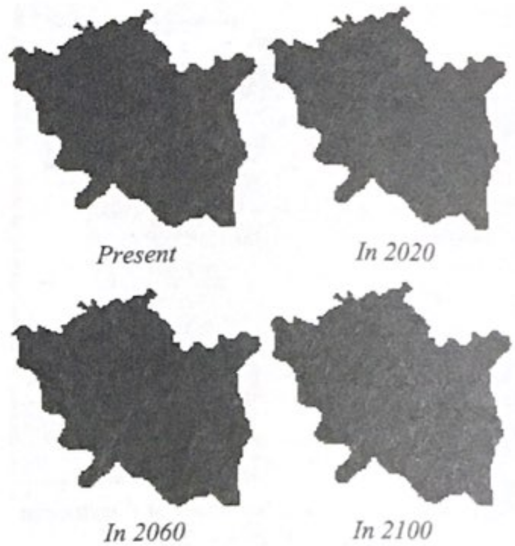

Fig 7. Distribution of salt-fresh water boundary of q_p aquifer over time

Forecast results indicate that by 2100, water levels in the Holocene aquifer will decreases by an average of 0.5 to 0.8 m (Q158). Moreover, the water level in the Pleistocene aquifer is lowered significantly, but mainly due to water exploitation. According to forecasts, the water standards of the qp aquifer until 2100 will reduce to nearly 10 m.

Basing on the results of forecasting the shift of salt - current boundaries and the change of water level, the author has calculated the area of saltwater of aquifers over time as shown in Table 1 below.

Table 1. Saline area of the aquifer over time

Unit: square kilometer

Time		Saline area of aquifers	
		Holocene aquifer	Pleistocene aquifer
Year	Present	521.132	905.375
	2020	505.007	907.595
	2060	453.99	917.270
	2100	417.64	928.940
Period	Present - 2020	16.13	2.20
	2020 - 2060	51.02	9.675
	2060 - 2100	36.35	11.67

4. CONCLUSION

Groundwater in Quaternary sediments of Thai Binh province is affected by climate change and sea level rise. In which the qh aquifer is affected more directly and powerfully than the qp aquifer.

Area of saline water in the qh aquifer is being narrowed, which in 2014 reduced by 180 km^2 compared to 1996, while the qp aquifer is changed not much.

The Holocene aquifer is influenced by rainwater, river water, and sea water. The amount of rainwater added to the qh aquifer during the rainy season is about 25 ÷ 27%. The total amount of water replenished for qh aquifer is about 345,460 m^3/day. When the sea level rises by 10%, the water level underground in the qp aquifer increases to 3.5 ÷ 4% compared to the current average water level.

By using Visual Modflow model and Seawat code can be simulated groundwater flow and the movement of salt and fresh water boundaries under the impact of climate change and sea level rise. So that estimate the saline area of aquifers in the future. Forecast to 2100, the area of salt water of Holocene aquifer will be increased about 104 square kilometers, but the Pleistocene aquifer will not be changed much.

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