Spatio-temporal variation of groundwater levels in Pleistocene confined aquifers in the Red River Delta, Vietnam

(23)

○Duong Du BUI, Akira KAWAMURA, Hideo AMAGUCHI, and Naoko NAKAGAWA

Department of Civil and Environmental Engineering, Tokyo Metropolitan University, 192-0397, Tokyo, Japan

1. Introduction

Groundwater plays a very significant role in the supply of water for human activities. Achieving sustainable management of groundwater resources is one of the essential objectives for the future of a country, especially when the rising demand for clean drinking water is considered. As monitoring and interpreting changes in groundwater levels are essential for groundwater management, a great deal of studies on spatio-temporal variation of groundwater levels has been carried out for many parts over the world, especially for urbanized areas in developed countries.

The Red River Delta (RRD) is one of two biggest deltas in Vietnam. People living in the delta depend heavily on groundwater for their domestic water because of the uneven distribution and unfavorable quality of surface water resources. The rapidly increasing amount of groundwater abstraction is mainly from shallow Pleistocene confined aquifers (PCA). Excessive groundwater exploitation without wise management and adequate understanding of groundwater level behaviors has caused some serious problems, such as: groundwater pollution, groundwater level decline, land subsidence, and seawater intrusion (Tong 2007). However, a fairly wide groundwater monitoring network in the Delta was not set up until 1995, and there has not yet been any analysis of variability of groundwater levels in the Delta due to the lack of available data. This paper investigated spatio-temporal variation of groundwater level (1995- 2009) in 63 wells for PCA in the delta. The expected outcomes will provide a basis for further groundwater analyses needed to ensure the sustainable groundwater development.

2. Materials and Methods

Study area: The RRD (about 13,000km^2) as shown in Fig. 1 is the most developed area in northern Vietnam with its population of about 19 million (2007). The delta belongs to tropical monsoonal areas with annual rainfall of about 1,600 mm in which 75% is rainfall in rainy season (May to Oct.). The annual average humidity, temperature, and evaporation are about 80%, 24^{o}C, and 900 mm, respectively. The tidal range along the coast is around 4m. The river network is quite dense but surface water has been seriously polluted. Groundwater thus becomes a main source of water supply (almost 100% in Hanoi), and it mainly is pumped from PCA (Tong, 2007).

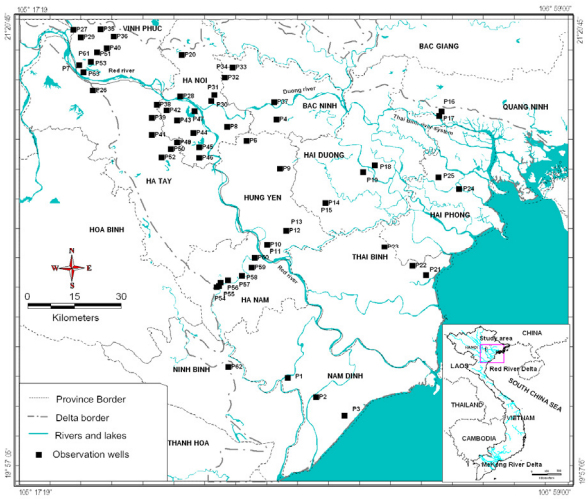

Fig. 1 Study area and observation well network

Data used: The reliability of groundwater analyses strongly depend on the availability of a large volume of high-quality data. Hence, we made the best use of observed groundwater level data during 15 years (1995-2009) in all 63 observation wells over the delta as shown in Fig. 1. This selection was based on the following criteria: (1) there are at least 15 years of record; (2) there is no more than 5% missing data; and (3) data are observed for PCA, not for other minor aquifers. Regarding observation intervals, the numbers of wells with the intervals once per day, once per three days, and once per six days are 11, 30, and 22, respectively. As shown in Fig. 1, the selected observation wells are widely distributed over the study area.

Methods: To achieve the objectives of this paper, graphs of groundwater levels and their monthly box- whisker plots at every well were established first as to get the initial impression of seasonality and trends. Then efforts have been made to clarify the spatial distribution of annual water levels during the 15 years by using the Kriging interpolation method and Geographic Information Systems (GIS). Even though those methods were used, creating sensible contour maps was a difficult task because the information from the wells are very small features on the scale of the

heterogeneities of an aquifer. We, therefore, not only utilized the methods but also interpreted and compared their results to observational data to draw the realistic contour maps.

3. Results and discussion

Fig. 2 shows selected monthly water levels (1995-2009) in 3 out of 63 wells along with their monthly box-whisker plots. It is apparent from Fig. 2 that the annual cycle of water levels is highly pronounced. Our earlier study indicated that this behavior is closely associated with the annual cycles of rainfall and the river water levels (Tong 2007). The three time series graphs reveal three typical long-term trend patterns for water levels. The P2 time series show a strong downward trend with an ambiguous annual cycle which is generally observed in highly-urbanized areas like Hanoi, Haiphong, Namdinh. The P20 time series present a slight downward trend with an annual cycle that is commonly located in less urbanized areas. The P53 time series reveal an ambiguous trend with an obvious annual cycle that is commonly found in recharge areas of groundwater (in the margins of the delta). Their box-whisker plots in the Fig. 2 show median, quartiles of 25% and 75%, maximum and minimum of the monthly water levels. These plots indicate the different levels of seasonality among three wells. The P20 and P53, but not P2, show the highest water levels in August. The strong decline trend in P2 might diminish the seasonality.

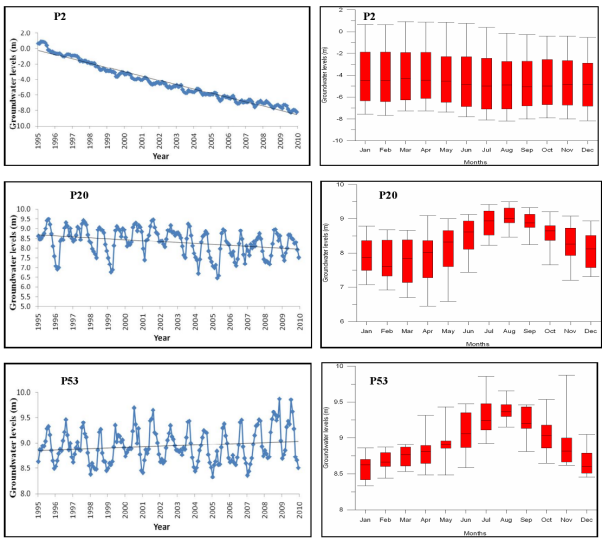

Fig. 2 Monthly groundwater levels at three selected wells along with their monthly box- whisker plots

Futhermore, Fig. 3a-b show the two selected countour maps of groundwater levels in 1995 and 2009, respectively. As shown in these figures, the flow patterns are quite similar to each other, in which flow direction is generally from northwest to southeast corresponding to the delta topography. Large cones of depression had already existed in 1995 in urban areas (Hanoi, Haiphong, and Namdinh) and they much expanded in 2009. The maps for the other years, which were not presented here, indicated year-by-year expansions of the cones.

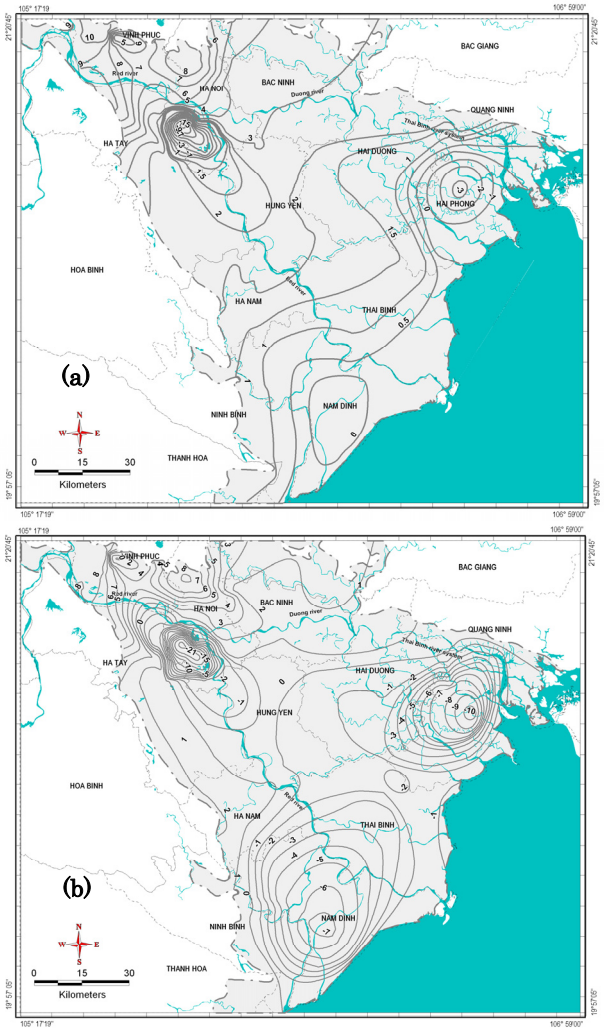

Fig. 3 Contour map of annual groundwater levels in 1995 (a) and in 2009 (b)

4. Conclusion

Analyses of spatio-temporal variation in this paper revealed several interesting features of fluctuation regime of groundwater level in Pleistocene confined aquifer in the Red River Delta, Vietnam. Besides the annual cycle of water levels, three typical long-term trend patterns of water levels were pronounced. In addition, distinct regional patterns were highlighted through analyzing contour maps of annual water levels during 15 years. This paper indicated an overall flow from inland to the sea except for 03 expanding cones of depression in urban areas of Hanoi, Haiphong, and Namdinh. The findings are fundamentals for sustainable groundwater development in the delta.

5. References

Tong, TN (2007) Groundwater level changes in the Red River Delta. PhD. Thesis. University of Geology and Mining, Vietnam, 150 p (in Vietnamese)

Keywords: *Spatio-temporal variation, groundwater level, confined aquifers, the Red River Delta, Vietnam*