Trend analysis of confined and unconfined groundwater levels in the Red River Delta, Vietnam by non-parametric test

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1. Introduction

People living in the Red River Delta (RRD), Vietnam, depend entirely on groundwater for their domestic water. Groundwater level has been seriously declined in various areas (Tong, 2007). Monitoring and interpreting changes in groundwater levels is essential for sustainable management of groundwater resources. Groundwater levels are often the most important information about the hydrogeological conditions of aquifers. Furthermore, world-wide interest in climate changes has led to numerous trend detection studies. Detection of changes in hydrological time series is an important and difficult issue of interest. The current works mainly focused on climate and surface water. In contrast, there have been very few investigations on detection of trend of groundwater level due to lack of available data. In Vietnam, we have been nominated to firstly implement a Nation-wide Groundwater Monitoring Program (NGMP) since 1995. These data observed by NGMP are vital for groundwater analyses but now not open to public yet. Using these valuable data, this paper explored the trend of groundwater levels in the whole RRD utilizing non-parametric Mann-Kendall (MK) test. The findings are indispensable for further groundwater analyses needed to ensure the sustainable groundwater development, but have never been completed before due to the unavailability of basic data.

2. Materials and Methods

Study area: The RRD (about 13,000km^2) as shown in Fig. 1 is the most developed area in the north of Vietnam with its population of about 19 million (2007). The delta belongs to the tropical monsoonal area in which rainfall in rainy season occupies 75% of annual rainfall (1,600 mm). The annual average humidity, temperature, and evaporation are about 80%, 24^{o}C, and 900 mm, respectively. The tide range near the delta is approximately 4m. The surface network is quite dense but surface water has been seriously polluted. Groundwater thus becomes a main source of water supply (almost 100% in Hanoi). Groundwater mainly is pumped from two aquifers, Holocene unconfined aquifer (HUA) and Pleistocene confined aquifer (PCA) (Tong, 2007).

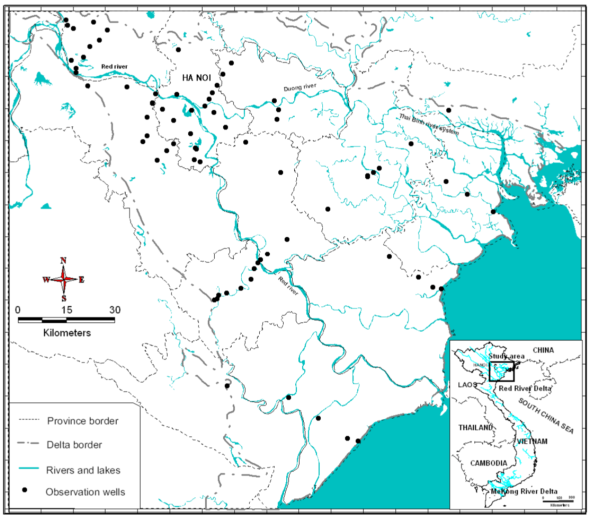

Figure 1: Study area and observation well network

Data used: The reliability of groundwater analyses strongly depend on the availability of a large volume of high-quality data. To take advantage of the data from the NGMP, we made the best use of all observed groundwater level data of a network of 77 stations (111 observation points) over the delta as shown in Fig. 1. Among these, groundwater levels of HUA and PCA monitored at 55 and 56 observation points, respectively. The record lengths were different but mainly from January, 1995 to December, 2005. Observation intervals were also not equal, roughly once every three days till 1999 but once a day since 2000. Data were tested for rainy, dry seasons, and all data.

Method: The non-parametric Mann-Kendall test, given by (1), was found to be an excellent tool detecting trends in hydrology (Burn and Elnur, 2002)

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \operatorname{sgn}(x_j - x_i) \quad \operatorname{sgn}(\theta) = \begin{cases} 1, \theta > 0 \\ 0, \theta = 0 \\ -1, \theta < 0 \end{cases} \quad (1); \qquad u = \frac{(S+m)}{\sqrt{V(S)}} \quad m = \begin{cases} -1, S > 0 \\ 0, S = 0 \\ 1, S < 0 \end{cases} \quad (2)$$

$$V(S) = \frac{1}{18}\left\{ N(N-1)(2N+5) - \sum_{1}^{n} e_i(e_i - 1)(2e_i + 5) \right. \quad (3); \qquad \beta[m/day] = Median((x_j - x_i)/(t(j) - t(i))) \quad (4)$$

Where x_i and x_j are the sequential data values, N is the data length, n is the number of tied groups, e_i is number of data in i^{th} (tied) group (i = 1 ~ n). The test has two important parameters: the significance level that indicates the trend's strength (S, u, $V(S)$); and the slope magnitude estimate (β) that indicates the direction as well as the magnitude of the trend. Note that in this paper we utilize (4) to estimate slope magnitude with different time interval.

3. Trend analysis of groundwater level

The trend test results were showed in Table 1. The hypothesis of upward and downward trends is based on 5% and 1% of u value for significance and weak trends. If it does not meet these levels, the trend can be rejected. Table 1 reveals that PCA has the same result for rainy, dry seasons and all data, indicating a strong decline in 54 out of 56 stations. In contrast, HUA show both downward and upward trends with similar results for rainy, dry seasons, and all data.

Furthermore, we examined β spatial distributions utilizing Kriging gridding method. Figures 2, 3, and 4 show the results of HUA and PCA for rainy season, dry season, and all data, respectively. From Fig. 2(b), 3(b), and 4(b), PCA has been declining over the delta at any time. The strong decline particularly shows in Hanoi and the coastal areas. Fig. 2(a), 3(a), and 4(a) reveal the different trends between HUA and PCA. Groundwater levels of HUA tent to increase in the northern and coastal areas. The groundwater level rise here could be caused by effects of sea level rise and irrigated water accumulation. Strong decline were found around the center of RRD for both HUA and PCA due to heavy pumping.

Table 1: Mann-Kendall trend test results

	HUA (55 stations)			PCA (56 stations)		
	Rainy	Dry	All	Rainy	Dry	All
Strong increase	17	19	19	1	1	1
Weak increase	2	3	0	0	0	0
No trend	9	7	9	1	1	1
Weak decrease	3	0	1	0	0	0
Strong decrease	24	26	26	54	54	54

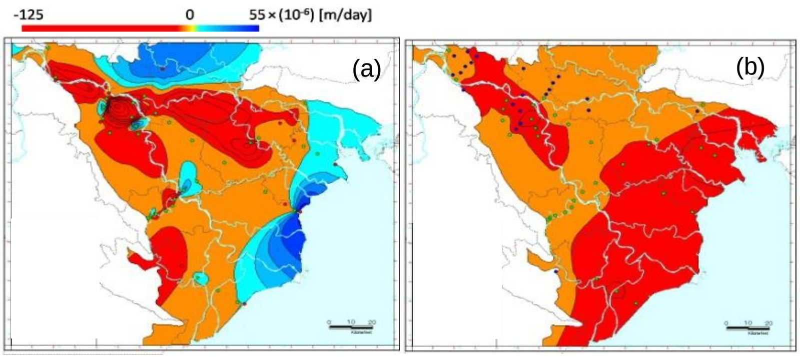

Figure 2: Slope magnitudes of (a) HUA and (b) PCA for rainy season

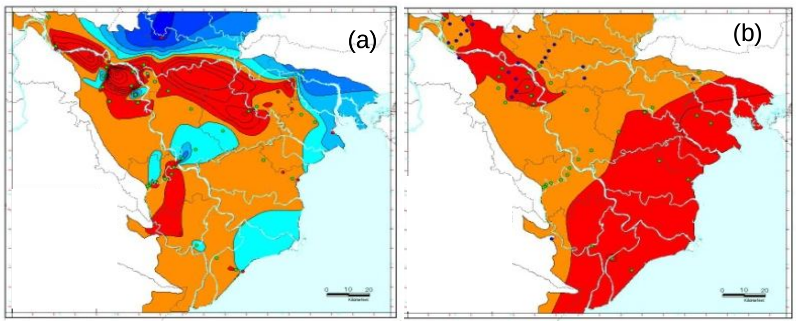

Figure 3: Slope magnitudes of (a) HUA and (b) PCA for dry season

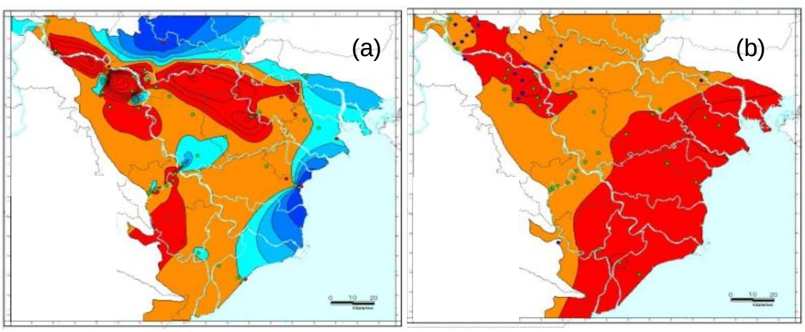

Figure 4: Slope magnitudes of (a) HUA and (b) PCA for all data

4. Conclusion

This paper analyzed groundwater level trends in the whole Red River Delta, Vietnam. As for the results, Pleistocene confined aquifer (PCA) groundwater level tends to decrease all the time that indicates the strong downward trend, especially in Hanoi and the coastal areas. However, groundwater level trends of Holocene unconfined aquifer (HUA) are quite different. HUA has strong upward trends in the northern and coastal areas but shows strong downward trends similar to PCA in the center due to heavy withdrawals from both aquifers. These findings are fundamentals for sustainable development of groundwater resources in the delta.

5. References

Burn, D.H. and Elnur, M.A.H., 2002. Detection of hydrologic trends and variability. Journal of Hydrology, 255, 107-122.

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