

学 位 論 文 要 旨

論文題名

(英語) Characterization of the aquifer system and groundwater level trends in the Red River Delta of Vietnam

(日本語) ベトナム紅河デルタにおける帯水層構造および地下水位トレンドの特性評価

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(学位論文要旨)

In the world, groundwater is the largest and most important source of potable water. Achieving sustainable management of groundwater resources is one of the essential objectives for the future of developing countries, especially when the rising demand for clean drinking water is considered. Groundwater management is particularly important in the Red River Delta, one of the two biggest deltas in Vietnam including the capital of Hanoi, because water supply in the delta greatly depends on groundwater due to the uneven distribution and unfavorable quality of the surface water. Aside from excessive groundwater exploitation and unwise management, inadequate understanding of the aquifer system and groundwater level characteristics has caused serious problems, such as drying up of shallow wells, water level decline, land subsidence, and groundwater pollution which threaten sustainable groundwater development in the delta.

Therefore, it is essential to investigate the spatial characteristics of the aquifer system and groundwater level trends in order to provide fundamental references for further groundwater analyses ensuring sustainable groundwater development in the Red River Delta. The main objectives of this study are: (1) to identify the aquifer framework and determine characteristics of the aquifer system in the delta; (2) to clarify the variation and spatial patterns of recent trends in groundwater levels of the identified aquifers. To achieve these goals, regional hydrogeological and groundwater monitoring databases for the entire delta were established, and then the aquifer system was identified and characterized by analyzing well logs and pumping test data. The non-parametric Mann-Kendall trend test and Sen's slope estimator were then utilized to detect possible trends and their slopes in groundwater levels. Finally, spatial patterns of the trends and trend slopes were elucidated using Geographic Information System (GIS) and geo-statistical techniques.

This dissertation is composed of five chapters.

Chapter 1 is the introduction which contains the background, motivation, and objectives of this study. A comprehensive review of literature as well as a description of scopes and methods were also presented.

In chapter 2, the study area and data used in this study were described, taking into account the general geographic and hydro-climatic characteristics of the Red River Delta. This chapter also provided brief descriptions about establishment of National Hydrogeological Database, National Groundwater Monitoring Network, and National Groundwater Monitoring Database in Vietnam.

From the Hydrogeological Database established, well log data (mostly about geologic strata, materials, and geological ages) of 778 boreholes in the Red River Delta were used to identify the aquifer frameworks, and then field data from 637 pumping tests out of 778 boreholes including specific capacity, specific yield of unconfined aquifers or storage coefficient of confined aquifers, and hydraulic conductivity or transmissivity were used to characterize the aquifer system and to estimate groundwater potential of each aquifer. Furthermore, groundwater levels during a period of 15 years (1995-2009) in 120 observation wells were selected from the Groundwater Monitoring Database for detecting their recent trends.

In chapter 3, the aquifer systems of the Red River Delta were identified and characterized. Comprehensive analyses of borehole data (i.e. well logs and hydrogeological parameters) for potential groundwater resources were conducted by creating and analyzing hydrogeological maps, cross sections, and contour maps of main aquifers' thickness and transmissibility. It was found that groundwater mainly exists in Quaternary unconsolidated sediments as porous water forming the topmost Holocene unconfined aquifer (HUA) and the shallow Pleistocene confined aquifer (PCA) sandwiching the Holocene-Pleistocene aquitard (HPA). Cleft and karst water exist in consolidated Neogene formations and Mesozoic rocks constituting the Neogene water bearing layer (NWL) and Mesozoic fractured zones (MFZ), respectively. It was also revealed that PCA and HUA are almost entirely distributed over the delta, and they serve as the highest groundwater potential and the most important aquifers for water supply. NWL and MFZ, which are placed below PCA but exposed on the surface outside the delta, are minor sources for local domestic water supply only.

In chapter 4, spatial patterns of recent trends in groundwater levels and their slopes were investigated for two main aquifers (i.e. HUA and PCA) by utilizing the non-parametric Mann-Kendall trend test and Sen's slope estimator. At each well, 17 time series (i.e. annual average, rainy and dry season average, annual maximum and minimum, and 12 time series for each month across years) were computed from the original record of groundwater levels, and then used for trend analysis.

Before conducting the trend analysis, this study carried out some preliminary analyses to get an initial understanding of groundwater level fluctuation. These analyses indicated an overall flow from northwest to southeast (from inland to the sea) corresponding to the delta topography for both HUA and PCA. HUA has formed a cone of depression in Hanoi during the past 15 years, while large cones of depression of PCA had already existed in 1995 in urban areas (Hanoi, Haiphong, and Namdinh) and they were greatly expanded in 2009.

The results of the trend analysis of the annual time series revealed that 35% of the wells for HUA showed downward trends, while about 21% showed upward trends. Spatial analysis has highlighted that strong downward trends were mainly in Hanoi with slopes of about 0.3 m/year, whereas upward trends were found in coastal region, Hungyen province, and northern parts of the delta with slopes of around 0.1 m/year. On the other hand, the study revealed that groundwater levels of PCA have decreased in almost all wells with average slope of about 0.2 m/year. There was no upward trend at all. The areas which showed serious downward slope of more than 0.3 m/year have occupied almost 3,400 km² (about 25% of the delta). Although the trend results for the 17 time series at a given well were quite similar, different trend patterns were detected in several time series.

The chapter 5 presents overall conclusions, recommendations for groundwater management, and future works.

研 究 業 績 一 覧

*印は、本論文に直接関係するものを示す

1. 論文 (査読あり)

No.	論文名	掲載誌	巻, 号, 頁	発行年	著者名
1	Characteristics of groundwater resources in the Red River Delta, Vietnam	Journal of Water Resources and Environmental Engineering	No.7 pp.78-86	2004.11	C. M. Vu <u>D. D. Bui</u>
2	The possibility of artificial recharges to groundwater resources in Hanoi, Vietnam	Journal of Water Resources and Environmental Engineering	No.7 pp.111-122	2004.11	T. N. Tong <u>D. D. Bui</u>
3	Extended application of MODFLOW model to study hydrogeology of coal mines in Quang Ninh province.	Journal of Water Resources and Environmental Engineering	No.7 pp.294-302	2004.11	C. M. Vu <u>D. D. Bui</u>
4	Assessment on the groundwater characteristics in the Red river delta serving the daily water exploitation	Journal of Agriculture and rural development	No.58(2) pp.45-53	2005.4	C. M. Vu <u>D. D. Bui</u>
5	Current status of arsenic contamination of groundwater in the HaTay province, Vietnam	Journal of Geology	No.295 pp.20-27	2006.6	C. M. Vu <u>D. D. Bui</u>
6	Numerical modeling for assessing impacts of Mong Duong thermal power factory to hydraulic regimes and inundated areas in the downstream of the Mong Duong River, Quang Ninh, Vietnam	Journal of Water Resources and Environmental Engineering	No.14 pp.54-60	2006.8	<u>D. D. Bui</u> T.T. Phan
7	Application of MIKE package to assess hydraulic regimes and flood mapping when construction of thermal power at the Mong Duong estuary (Quang Ninh)	Journal of Water Resources and Environmental Engineering	pp.13-20 Special issue	2007.8	C. M. Vu <u>D. D. Bui</u>
8	Sustainable development in the mining sector and its evaluation using Fuzzy AHP (Analytic Hierarchy Process) approach	Journal of Geosystem Engineering	No.14(1) pp.43-50	2011.3	N.T. Bui K. W. Kim L.Prathumratana K. Y. Lee T.H. Kim S.H. Yoon M. Jang <u>D.D. Bui</u>
9*	Trends in hydroclimatic series in Thua Thien Hue province, Vietnam: 1. Rainfall and rainy days	Sustainable Urban Regeneration	No.8 pp.40-43	2011.3	<u>D. D. Bui</u> C. M. Vu H. S. Nguyen A. Kawamura D. M. Vu T. T. Nguyen
10*	Aquifer system characterization for potential groundwater resources in Hanoi, Vietnam	Hydrological processes	Accepted		<u>D.D. Bui</u> A. Kawamura T.N. Tong H. Amaguchi T.M. Trinh

11*	Identification of aquifer system in the whole Red River Delta, Vietnam	Geosciences Journal	Accepted		<u>D.D. Bui</u> A. Kawamura T.N. Tong H. Amaguchi N. Nakagawa Y. Iseri
12*	Recent trends in groundwater levels in Hanoi, Vietnam	Hydrological processes	Submitted		<u>D.D. Bui</u> A. Kawamura T.N. Tong H. Amaguchi N. Nakagawa
13*	Tempo-spatial analyses of recent trends in groundwater levels in the Red River Delta, Vietnam	Hydrogeology Journal	Submitted		<u>D.D. Bui</u> A. Kawamura T.N. Tong H. Amaguchi N. Nakagawa

2. 国際会議

No.	論文名	掲載誌	巻,号,頁	発行年	著者名
1	Assessment of saline water intrusion into estuaries of Red-Thai Binh River during dry season having considered water released from upper reservoirs and tidal fluctuation	Proceedings of the Vietnam-Japan Estuary Workshop 2006, Hanoi, Vietnam	pp.12-19	2006.8	C. M. Vu <u>D. D. Bui</u>
2	Research on the groundwater pollution and its effect on the community health in Hanoi, Vietnam with the support of GIS and mathematical model	Proceedings of the 2 nd International Conference on the Development of Biomedical Engineering in Vietnam, Hanoi, Vietnam	pp.338-343	2007.7	<u>D.D. Bui</u> H.T. Do H.A. Hoang N.T. Bui
3	Application of mike package to assess hydraulic regimes and flood mapping when construction of thermal power at the Mong Duong estuary (Quang Ninh)	Proceedings of the Vietnam- Japan Estuary Workshop 2007, Ho Chi Minh City, Vietnam	pp.13-20	2007.8	C.M. Vu <u>D.D. Bui</u>
4*	Hydrogeological framework for potential groundwater resources in Hanoi, Vietnam	Proceedings of International Conference on Hydrology and Disaster Management, Wuhan, China	pp.192-197	2009.11	A. Kawamura <u>D.D. Bui</u> T.N. Tong H. Amaguchi N. Nakagawa
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6	Prevalence of arsenic in groundwater resources in Hanoi2, Vietnam	Proceedings of SEGHI 2010 International Conference on Environmental Quality and Human Health, Galway, Ireland	pp.51-52	2010.6	N.T. Bui K. W. Kim S. Suthipong <u>D.D. Bui</u>

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8	Spatio-temporal characteristics of one-minute rainfall in Tokyo	Proceedings of the Fifth Conference of Asia Pacific Association of Hydrology and Water Resources, Hanoi, Vietnam	pp.527-533	2010.11	H. Boda A. Kawamura J. Olsson H. Amaguchi N. Nakagawa <u>D.D. Bui</u>
9*	Recent trends and variation in groundwater levels of Holocene unconfined aquifers in Hanoi, Vietnam	Proceedings of the International Symposium Hanoi Geo-Engineering 2010, Hanoi, Vietnam	pp.159-168	2010.11	<u>D.D. Bui</u> A. Kawamura H. Amaguchi T.M. Trinh T.N. Tong
10*	Spatial decline distribution of groundwater levels of confined aquifer in the whole Red River Delta, Vietnam	Proceedings of World Environmental and Water Resources Congress 2011, Palm Springs, USA	pp.823-833	2011.5	<u>D.D. Bui</u> A. Kawamura T.N. Tong H. Amaguchi N. Nakagawa
11*	Trend detection in groundwater levels of Holocene unconfined aquifer in Hanoi, Vietnam by non-parametric approaches	Proceedings of World Environmental and Water Resources Congress 2011, Palm Springs, USA	pp.914-924	2011.5	A. Kawamura <u>D.D. Bui</u> T.N. Tong H. Amaguchi N. Nakagawa
12*	Trend analysis of groundwater levels of Holocene unconfined aquifer in the whole Red River Delta, Vietnam	The Second International MAHASRI/HyARC Workshop on Asian Monsoon and Water Cycle, Nha Trang, Vietnam	Submitted	2011.8	<u>D.D. Bui</u> A. Kawamura T.N. Tong H. Amaguchi N. Nakagawa
13*	Quantification of surface water and groundwater interactions in Hanoi, Vietnam by coupling MIKE 11 with MODFLOW	The Second International MAHASRI/HyARC Workshop on Asian Monsoon and Water Cycle, Nha Trang, Vietnam	Submitted	2011.8	T.T. Nguyen A. Kawamura C.M. Vu <u>D.D. Bui</u>

3. 口頭発表					
No.	論文名	掲載誌	巻,号,頁	発行年	著者名
1	Numerical model in estimation of groundwater balance in Red River Delta based on the relationship between surface and ground water resources	Proceeding of the 10 th Scientific Conference on Hydrology, Water Resources, and Environment, Hanoi Vietnam	pp.408-419	2007.3	T. T. Nguyen T. N. Tong <u>D. D. Bui</u>
2	Application of 3D numerical modeling for assessing and forecasting saltwater intrusion into groundwater at the Red River plain, Vietnam	Proceedings of 4 th Vietnamese -Japanese Students' Scientific Exchange Conference □ Kyoto, Japan	pp.245-246	2008.11	<u>D.D. Bui</u> C.M. Vu T.N. Tong N.T. Bui H. Do
3*	The Red River Delta, Vietnam: An overview of groundwater resources	The 36 th Conference of Japan Society of Civil Engineering, Kanto branch, Tokyo, Japan	CD-ROM: II-020	2009.2	<u>D.D. Bui</u> A. Kawamura H. Amaguchi
4*	ベトナム紅河デルタにおける不圧および被圧地下水位のトレンド解析	第 37 回土木学会関東支部研究発表会講演集	CD-ROM: II-020	2010.3	祭田佳奈江 河村 明 井芹慶彦 <u>D.D. Bui</u> 天口英雄 中川直子
5*	Trend analysis of confined and unconfined groundwater levels in the Red River Delta, Vietnam by non-parametric tests	Proceedings of 2010 Annual Conference, Japan Society of Hydrology and Water Resources, Tokyo, Japan	pp.98-99	2010.9	<u>D.D. Bui</u> A. Kawamura H. Amaguchi N. Nakagawa Y. Iseri
6*	Spatio-temporal variation of groundwater levels in Pleistocene confined aquifers in the Red River Delta, Vietnam	Proceedings of 2011 Annual Conference, Japan Society of Hydrology and Water Resources, Kyoto, Japan	Accepted	2011.8	<u>D.D. Bui</u> A. Kawamura H. Amaguchi N. Nakagawa
<p>上記のとおり相違ありません。</p> <p>平成 23年 6月 20日</p> <p style="text-align: right;">氏 名 Duong Du Bui (印)</p>					

※講演も記載すること。著者名は全員記載し、ご本人に下線を引いてください。
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主要論文に*など印をつけてください。

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