Hydrogeological Framework for Potential Groundwater Resources in the Whole Red River Delta, Vietnam

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Abstract

The Red River Delta is one of two biggest deltas in Vietnam. People living in the delta depend entirely on groundwater for their domestic water. However, the aquifer system in the whole Red River Delta remains poorly understood due to the lack of available data. Recently, we were nominated to construct a hydrogeological database. Using these valuable data contained in this database, this paper analyzed the best number of 778 boreholes including well logs for the first time in order to identify the entire hydrogeological framework for potential groundwater resources. Great efforts have been made to establish and analyze hydrogeological maps, cross sections. As for the results, we 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), while cleft and karst water exist in consolidated Neogene formations and Mesozoic rocks constituting a Neogene water bearing layer (NWL) and Mesozoic fractured zones (MFZ), respectively. PCA is widely distributed to about 80% in the southern part of the Delta. It serves as the highest groundwater potential and the most important aquifer for water supply. HUA is also widely distributed about 75% in the south and has a high groundwater potential. NWL and MFZ, placed below PCA but exposed in the border of the Delta, are minor sources for local domestic water supply only. These findings are indispensable for further groundwater analyses needed to ensure the sustainable use of groundwater resources for the high-security water requirements in the Delta, but have never been completed sufficiently before due to the unavailability of large-scale basic data sets.

Keywords: aquifer system, the Red River Delta, Vietnam, groundwater resources

Introduction

Sustainable management of groundwater resources is one of the essential objectives for the future of developing countries like Vietnam, especially when the rising demand for clean drinking water by these fast growing communities is considered (Mende et al., 2007). The Red River Delta including Vietnamese capital, Hanoi, the center of economy, culture, and politics for Vietnam is addressing this. Undue groundwater exploitation without the wise management and adequate understanding of the aquifer system characteristics have caused some serious problems, such as: drying up of shallow wells, decline of groundwater level, land subsidence, and groundwater pollution in this area (Tong, 2000, Bui, 2005).

Understanding and quantifying groundwater resources is a very complex and difficult task, considerably more problematic and uncertain than surface water hydrology. Groundwater investigations thus require a comprehensive understanding of the host geological formations (aquifers), and the hydrological processes which control the storage and movement of water within the subsurface. Although geophysical methods and remote sensing techniques can assist with hydrogeological interpretations, the most useful and reliable information is observed field data obtained from boreholes (Lewis et al., 2008).

Obtaining basic data adequately and understanding characteristics of the aquifer system are fundamental for the validity of other hydrogeological studies. Researchers in the world have done a great deal of studies aimed at identifying the aquifer system. Zhang et al. (2007) conducted a comprehensive analysis of basic hydrogeological data to clarify the aquifer system in the Southern Yangtse Delta, China in which hydrostratigraphic units of two aquifers and three aquitards with their hydrogeological properties were quantitatively characterized. Recently, Lewis et al. (2008) revealed the hydrogeological system of five distinctive hydrogeological systems as fundamentals before going to assess groundwater resources in the Broken Hill Region, Australia. Many other works demonstrating the necessities of portraying the aquifer system in the point of view of groundwater resources had been investigated in the Lower Mississippi Valley, USA (Boswell, 1996); Central

Kalimantan, Indonesia (Ludang et al., 2007); southeast coastal plain aquifers, North Carolina, USA (McCoy et al., 2007); the Bengal basin in India and Bangladesh (Mukherjee et al., 2009); an altered wetland in Jordan (Litaor et al., 2008); and, many others.

In Vietnam, there have been a large number of groundwater resource studies on the two biggest deltas, the Red River Delta and the MeKong River Delta, due to their important roles in the development of Vietnam (e.g., Agusa, et al., 2005; Berg et al., 2001, 2007; Funabiki et al., 2007; Kazama et al., 2007; Kohnhorst, 2005; Shinkai et al., 2007). Most of them were concerned about the origin, evolution, and development of the deltas, surface water and groundwater pollution, especially arsenic pollution, and they were limited to small local cites within the delta. There are few other original groundwater investigations for the Hanoi area existing in the literature (Trinh and Fredlund, 2000). However, no one has accomplished a comprehensive analysis of the entire Red River Delta aquifer system, while comprehensive understanding of the aquifer system and hydrogeological conditions is a key factor and prerequisite for those studies. So far, there has been no comprehensive analysis of the aquifer system and hydrological conditions within the entire delta due to the unavailability of basic data.

Initiating from these practical difficulties, we recently have implemented a National Hydrogeological Database Project under the support and nomination of the Department of Geology and Minerals of Vietnam as the first case where our investigation could put all the basic data together, especially borehole data, from various sources throughout the delta. In this paper, these internally-available data sets including well logs and their hydrogeological properties, such as: materials, aquifer thicknesses and depths, and so on were comprehensively analyzed for the entire delta.

To take advantage of our unique data sets as much as possible, the main objectives of this paper are to identify the aquifer system of the whole Red River Delta and characterize its hydrogeological properties adequately and quantitatively from the viewpoint of potential groundwater resources. To achieve the aims aforementioned, this work has focused on acquiring, compiling, and analyzing hydrogeological data from many field sites and from the highest number of existing boreholes, thereby establishing hydrogeological maps, cross-sections, and isopach maps of aquifer thickness. Once these findings are internationally documented, they could provide indispensable fundamentals and serve as basic reference for further hydrogeological studies in the delta.

Study area and data used

Study area

A delta is a landform that is formed from the deposition of the sediment carried by the river. Thus, the Red River Delta in this paper s defined as the area whose surface is cover with the sediments within the border as shown in Fig. 1. The Red River Delta has a surface area of about 13,000km^2 in the northern part of Vietnam, occupying 4.5% of total Vietnam area. It is the most developed area of Vietnam comprising 13 provinces and cities as shown in Fig. 1. The population is about 19 million in 2007, occupying 22% of the Vietnam population. Many important centers of economics in Vietnam, such as: Hanoi, Haiphong, and Namdinh are located there. The major type of topography is flood plain. The surface elevation of the delta is mainly below 12 m above mean sea level (MSL) with about 55% of less than 2 m.

The delta belongs to the tropical monsoonal area with two distinctive seasons. The rainy season is from May to October and the dry season lasts from November till April. The annual rainfall is about 1,600 mm of which rainfall in the rainy season occupies about 75%. The annual average humidity is about 80%, and the average temperature is around 24°C. Evaporation is quite high with the annual average of 900 mm (Tong, 2007).

The river network is quite dense in the delta with the density of about 0.7 km/km^2. The river slope is around 0.02-0.05m/km. Average discharge of the Red River at the Hanoi station is 385 m^3/s in the dry season and 14,800 m^3/s in the rainy season. The water of the Red River has high level of suspended load throughout the year. The amplitude of the tide in the China Sea area near the delta is approximately 4m. Surface water, especially in lakes, in some cities over the delta has been seriously polluted due to insufficiency of infrastructure and unwise management of dumping waste (Tong, 2007).

Groundwater thus becomes a main source of water supply in the delta. The amount of groundwater abstraction has been rapidly and continuously increasing. In Hanoi, for example, almost 100% of water supply is from groundwater. Some bio-chemical indexes like ammonia, microbe, heavy metal, arsenic concentration, and so forth have increased over the years (Agusa et al., 2005; Berg et al., 2001, 2007; Bui et al., 2007; UNICEF Vietnam, 2001).

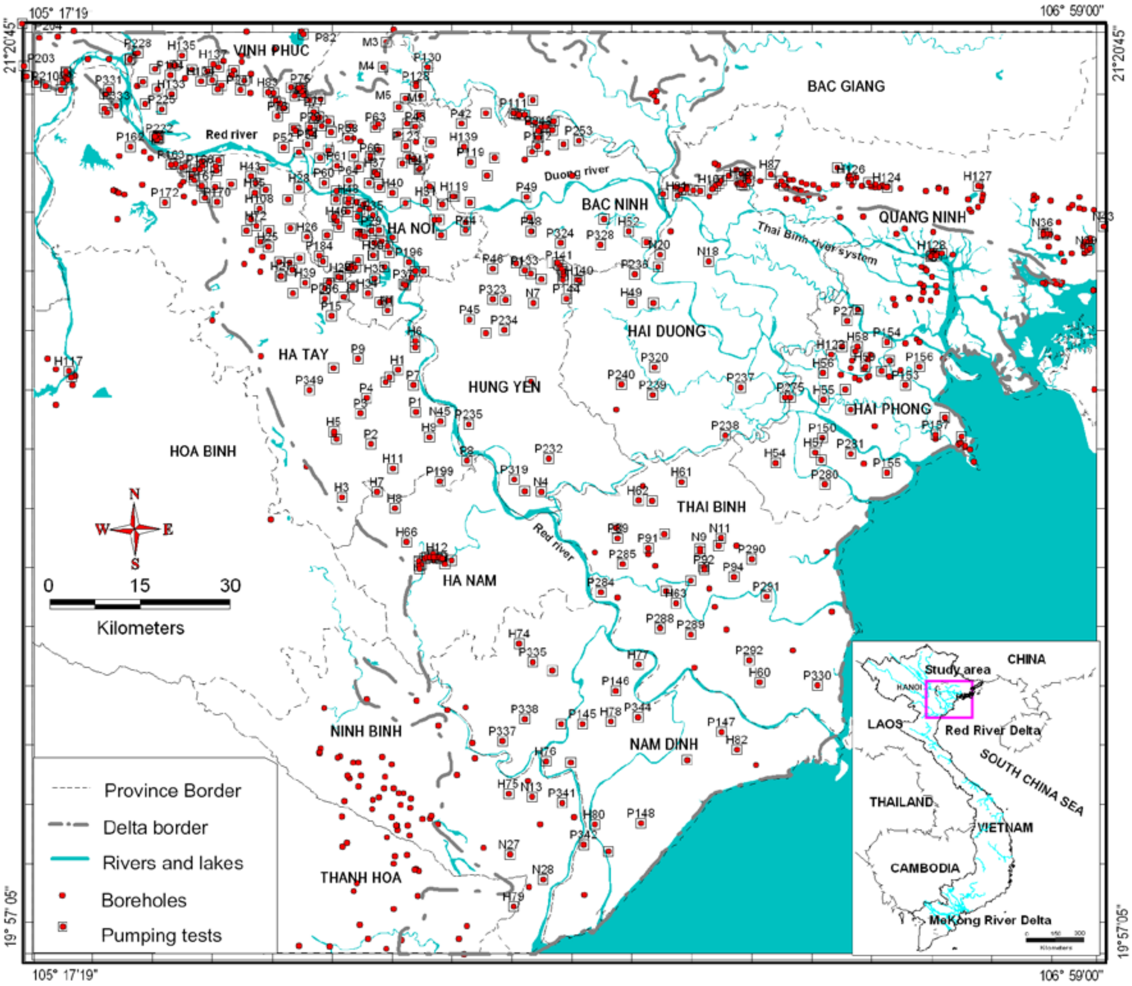

Figure 1. Location of study area and borehole distribution

Establishment of National Hydrogeological Database Project

The reliability and validity of groundwater analysis strongly depend on the availability of a large volume of high-quality data (Gogu et al., 2001). Data availability is also essential to develop complicated, integrated approaches for groundwater management and monitoring (Rossetto et al., 2007). In Vietnam, however, hydrogeological data are sparse, seldom systematically organized, and accessible to a very limited number of users. These primary data sets come from various sources, such as: Vietnamese geological survey departments, local to national environmental agencies, public and private research institutions, consultant firms, and many others. There are large differences in data format, quality, and storage media. This problem is an obstacle to the application of integrated groundwater management on a large basin scale.

A time-consuming and costly project named, the “National Hydrogeological Database Project” was therefore initiated under the Ministerial Decision which was a part of the Prime Minister’s own decisions (Prime Minister of Vietnam, 2001). The project lasted from 2002 to 2004 and cost 7.4 billion VND (1USD=15,000VND) in which Dr. Tong, one of the authors, was nominated as project leader to construct the GIS-based hydrogeological database. All basic data, both tables and maps, are managed and handled by a central computer program called HYDROGEOBANK. Details about this project and the database were described in the final report of the project (Tong, 2004).

Red River Delta has the densest hydrogeological data in Vietnam with a large number of data owners. Therefore, implementation of the database project in the delta was much more difficult and valuable than any of the others. The basic data about boreholes, dig wells, and springs with their hydraulic properties, such as: general, hydrogeological, stratigraphical, chemical, and borehole structural information was collected, integrated, and computerized from various sources. These valuable data sets maintain a vital role for further groundwater studies in the delta, but now are not open to public, just internally accessible by project-involved agencies and staff like us. Hopefully,

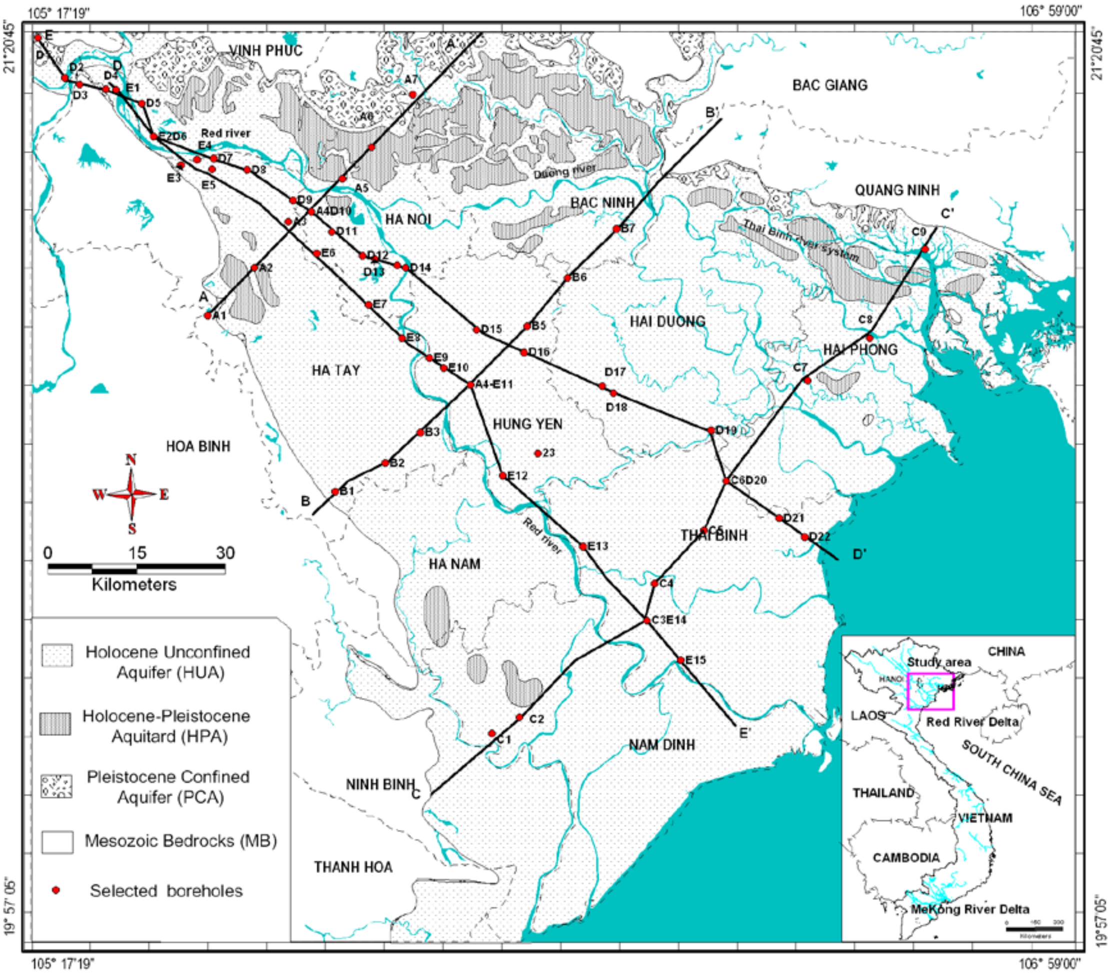

Figure 2. Surface hydrogeological map of the Red River Delta

these data sets will be available in the next stage, because without these data sets it is very hard to implement necessary groundwater analyses.

Data used

To take advantage of the data from our National Hydrogeological Database Project as much as possible, we made the best use of all the 778 boreholes as shown in Fig. 1 and hydrogeological survey data including geological map and their descriptions. The average density of boreholes over the delta is around 0.05 borehole/km2. One hundred boreholes reach their depth at Neogene-aged formations and 7 boreholes were drilled to a depth of Mesozoic-aged formations. The remaining 671 boreholes were drilled within Quaternary-aged formations. The boreholes were completed from 1966 to 2003 and mainly concentrated at developed cities, such as: Hanoi, Haiphong, Hatay as shown in Fig. 1.

Identification of hydrogeological framework

Hydrogeological map and cross-sections

In any hydrogeological investigation, the identification of aquifers and aquitards is needed to be properly understood. Distribution of aquifers and aquitards in a region is determined by the stratigraphic, lithological characteristics, and structure of the geological strata. Hydrostratigraphy involves the combination or separation of units with similar hydraulic conductivities into aquifers or aquitards. Hydrogeological mapping is an effective way to visually depict the hydrogeological characteristics beneath the surface of the land. Knowing a region's hydrogeological framework is fundamental to understand the occurrence and movement of groundwater. Several techniques are used in hydrogeological mapping for analyzing and correlating data from individual sites and depicting them as continuous data, in which hydrogeological map and cross-section are the techniques commonly used for visually depicting a hydrogeological system.

In this paper, first we gathered field data as stated in the former section, and then integrated them to gain visual demonstrations of the surface distribution of aquifers, resulting in drawing the surface hydrogeological map shown in Fig. 2. This figure reveals that HUA is the topmost aquifer and distributes widely with a total area of about 11,450 km2 occupying about 88% of the delta area. There is a confining layer, aged from Holocene to Pleistocene, named HPA, sandwiched between HUA and PCA. HPA is mostly located under HUA but exposed out on the surface around the northern border of the delta with total area of about 5% of the delta. PCA, placed under HUA and HPA, is distributed almost entirely the delta. Furthermore, there are only several small areas of PCA dispersedly present on the surface in the north. In the northern part of the delta, majority of PCA is just covered with HPA owing to the absence of HUA. In some other places, HPA has been thinned out. PCA directly is covered with HUA and they share a unique hydraulic head. Mesozoic bedrocks (MB) exposed on the surface of the ground create mountainous areas outside the border of the delta. Actually, MFZ, the fractured parts of MB, are distributed sparsely in small zones within MB which are difficult to see in Fig. 2.

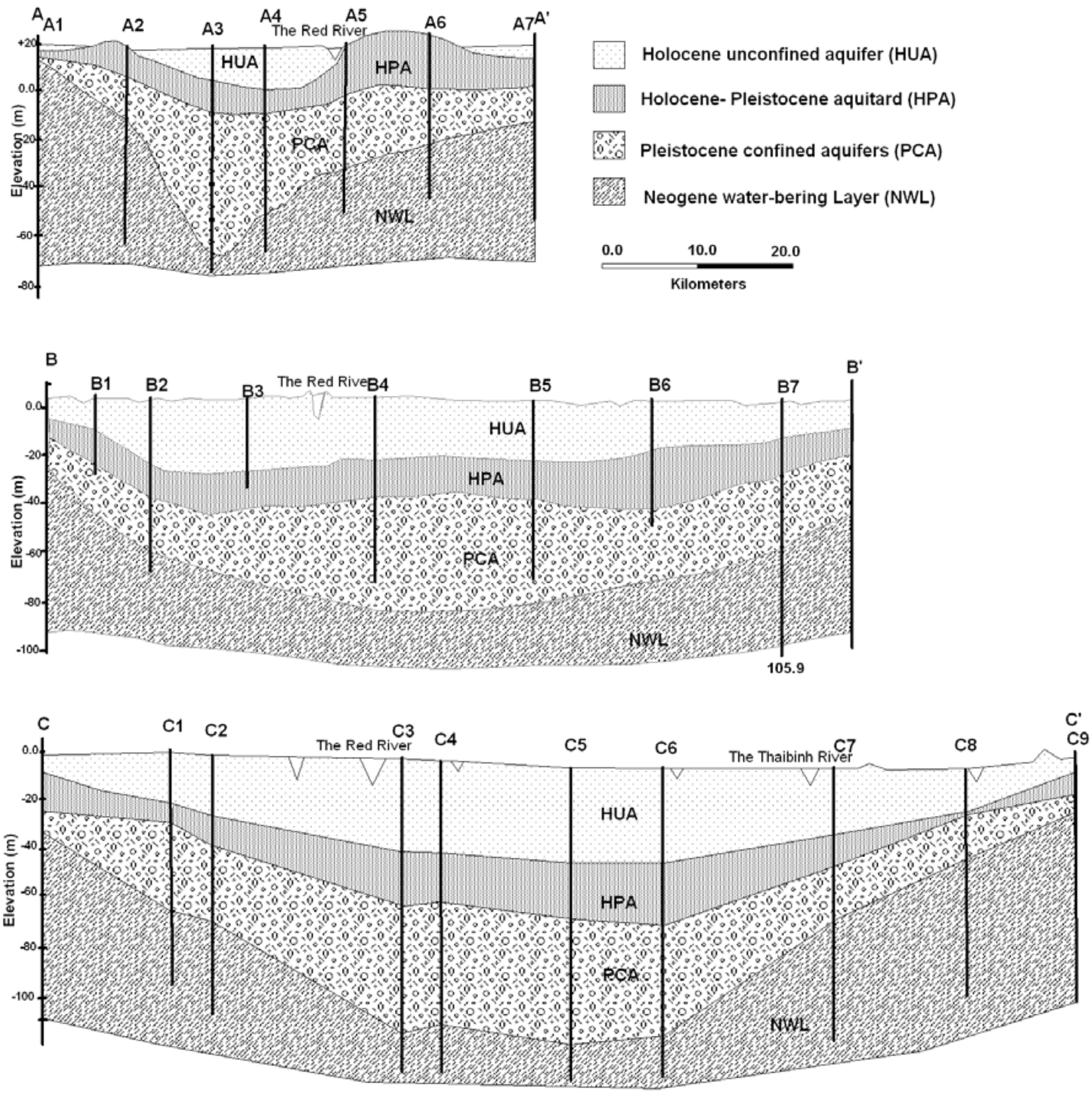

Figure 3. S Hydrogeological cross-sections along A-A', B-B', C-C' lines as shown in Fig. 2

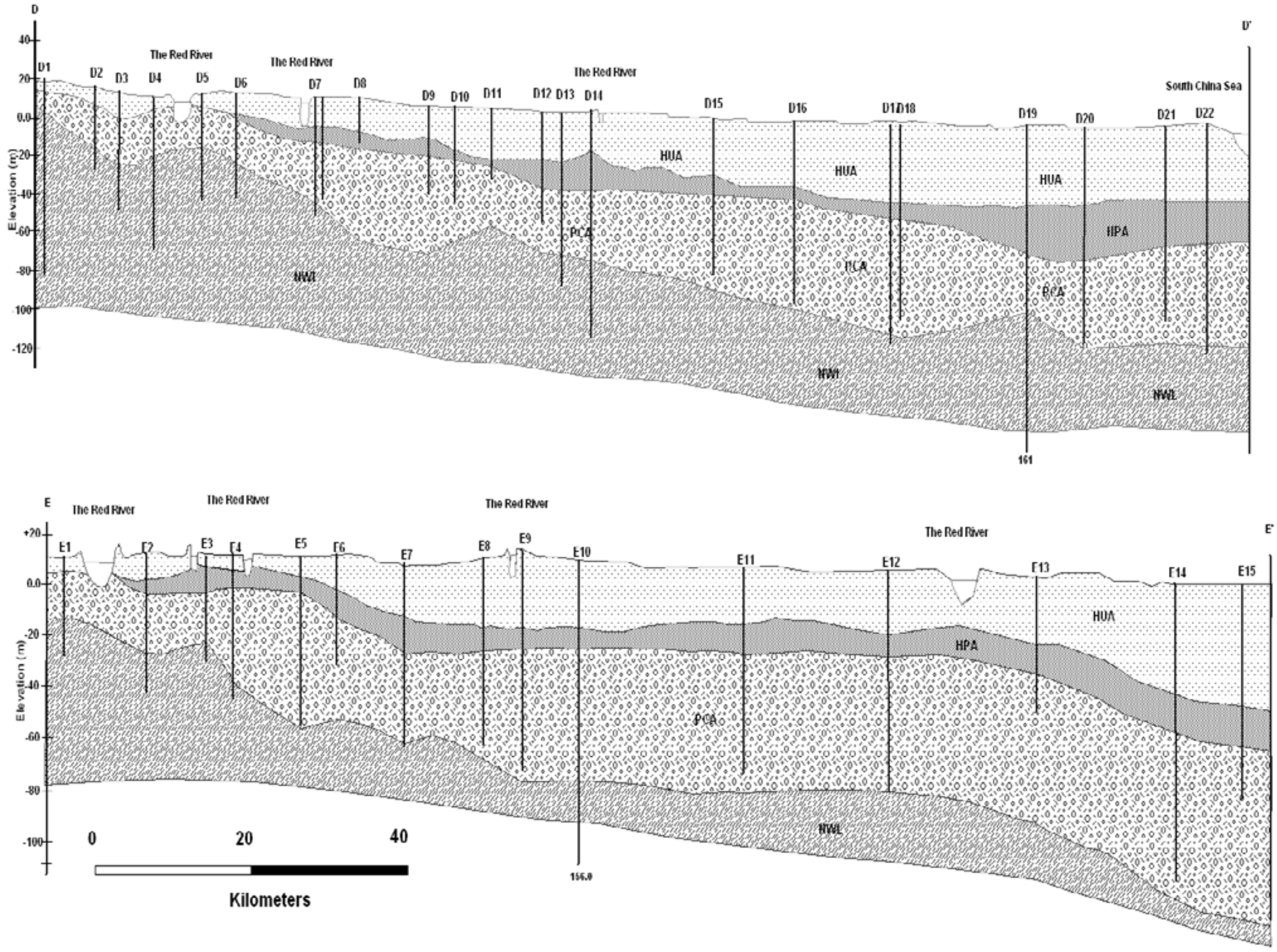

Figure 4. Hydrogeological cross-sections along D-D’, E-E’ lines as shown in Fig. 2

Furthermore, we hydrostratigraphically interpolated strata depth data from a number of well logs. By considering the density of boreholes and the absence of main aquifers in the border of the delta, cross-section lines A-A’, B-B’, C-C’ as lateral direction and D-D’, E-E’ as longitudinal direction were selected shown in Fig. 2 to draw hydrogeological crass-sections. Fig. 3 and Fig. 4 are the results of these cross-sections, in which A-A’, B-B’, C-C’, D-D’, E-E’ were made by interpolating 7, 7, 9, 22, 15 borehole columnar section data, respectively as shown in Fig. 3 and Fig. 4. These figures demonstrate a straightforward framework of the aquifer system and hydrogeological conditions in the delta.

Fig. 3, Fig. 4 indicated that the Red River Delta is composed of Quaternary-aged unconsolidated sediments with a maximum thickness of 100 meters, lying directly over the bedrocks aging from the Neogene period of the Cenozoic era to the Triassic period of the Mesozoic era. Groundwater of the Quaternary-aged sediments mostly exists as porous water forming the topmost HUA and the shallow PCA sandwiching HPA, while cleft and karst water exist in consolidated Neogene formations and Mesozoic rocks constituting NWL and MFZ. The Red River is an important natural recharge source for groundwater storage in the delta because it runs across HUA and in some places across PCA due to stream-bed erosion. In general, the main recharge sources of these aquifers are from river water, rainfall and irrigation water.

Geological formations and material ages from the collected well logs and geological description show that the delta has a complex geological setting. Quaternary-aged sediments have diversity of strata and lithological materials. The development of the delta’s geological condition was related to the accommodation, marine transgression and regression, and tectonic activities, so the sizes of sediments were mainly riverbed facies. Deposits usually have their origin in rivers, floods, lakes, marshes, seas, or modern alluvium. River-origin deposits commonly form aquifers (HUA and PCA) but sea-origin deposits build up aquitards or aquicludes (HPA). HPA are mainly composed of slightly permeable or impermeable formations like clay sand, clay, or silty clay mixing with black-gray plants or sandy shale. This aquitard distributes widely over the study area except for some trips along the riverside due to river erosion where the topmost HUA hydraulically connects to the shallow PCA. HPA thickness varies greatly, up to 40 m as shown in Fig. 3 and Fig. 4.

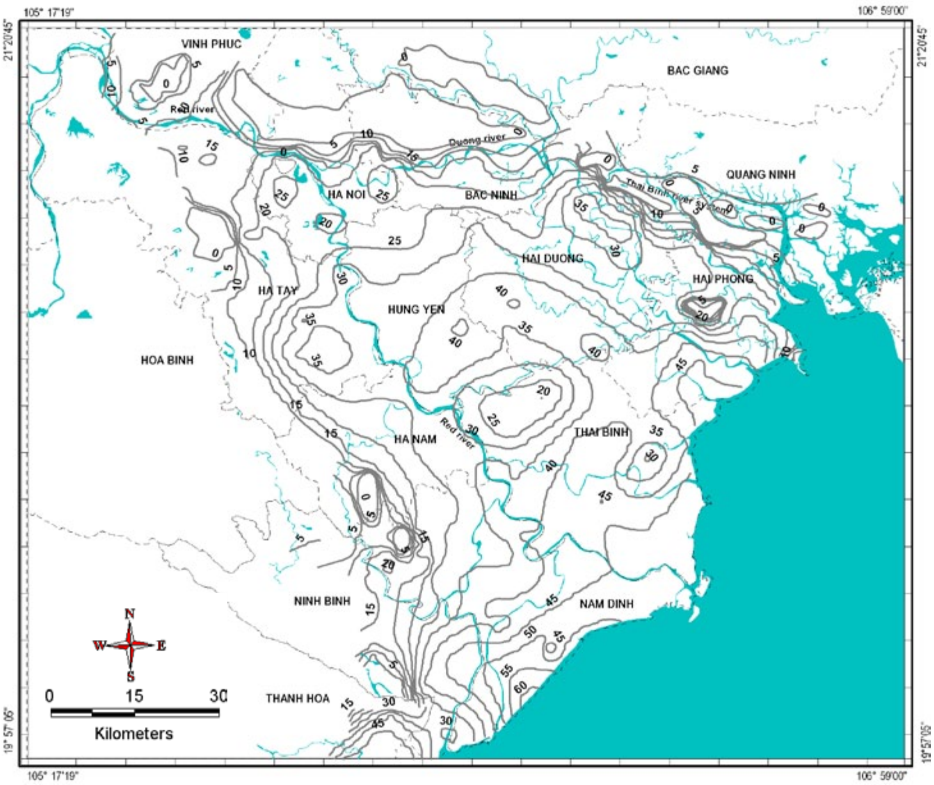

Figure 5. Isopach map of HUA's thickness (m)

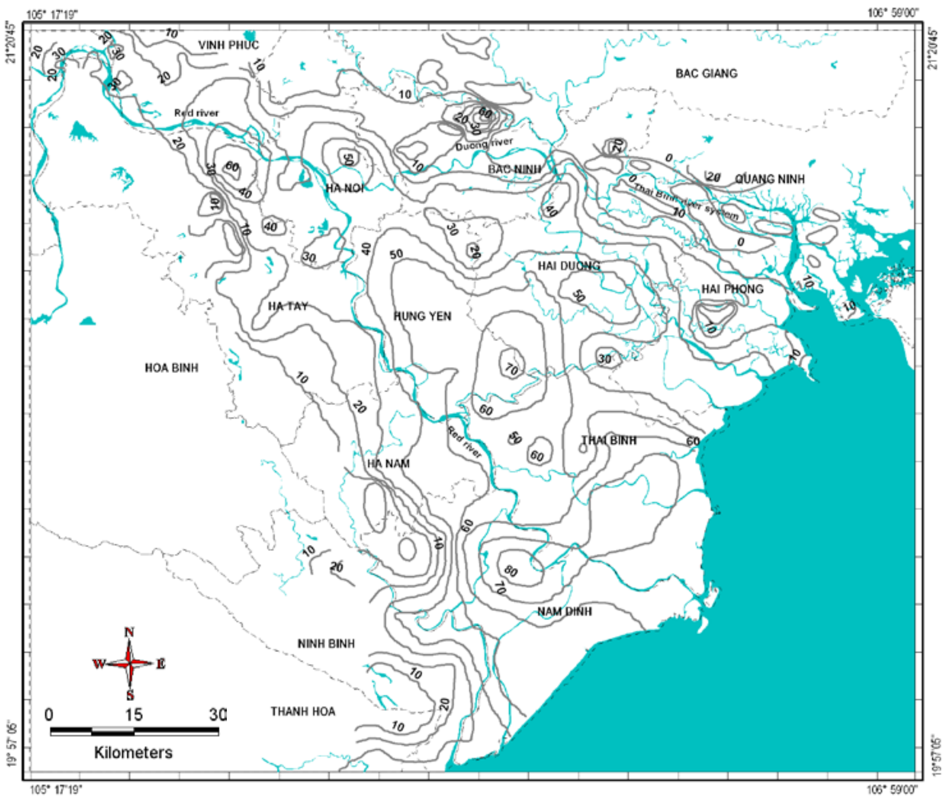

Figure 6. Isopach map of PCA's thickness (m)

Isopach maps of HUA and PCA

An isopach map is typically used to create a continuous picture from discrete sampling sites. Kriging is a geostatistical gridding method that has proven useful and popular in many fields. The isopach maps of HUA and PCA thickness were drawn using strata data from 721 well logs as shown in Fig.5 and Fig.6 respectively. From Fig.5, it is depicted that HUA aquifer thickness varies up to more than 60 m. On the whole, there is an increasing tendency from the northwest to the southeast of the delta. However, there is a thin area with its thickness of less than 30m in the middle of the delta. As shown in Fig. 5, the thickness is zero in the north and some other places at the border of the delta because there is no HUA in these areas as shown in Fig. 2. Fig.6 indicates that the thickness of the PCA also fluctuates over a large range, up to 80 m and has an increasing tendency from the northwest to the southeast of the delta. There are three areas of more than 60 m in thickness, which are located near the sea around Namdinh province, in the center of the delta, and in the west of Hanoi province.

Conclusions

The Red River Delta is one of two biggest deltas in Vietnam, where the people depend entirely on groundwater for their domestic water. In this paper, taking advantages of our recent project on constructing a National Hydrogeological Database, the best numbers of 778 boreholes including well logs were comprehensively analyzed for the first time in order to identify the aquifer system and characterize hydrogeological conditions in the entire delta from the viewpoint of potential groundwater resources. Hydrogeological data were interpolated and the aquifer system of the delta was identified by creating the hydrogeological map, hydrogeological cross sections, and isopach maps of aquifer thickness. As for the results, the delta is composed of Quaternary-aged unconsolidated sediments which consist of HUA, PCA and HPA, directly overlaying on the hard older formations which form the NWL and MFZ.

Also, we focused on analyzing hydrogeological characteristics of these water bearing formations, especially HUA and PCA in more detail by making isopach maps of thicknesses. We found that PCA is distributed almost entirely the delta. The thickness of the PCA changes considerably, up to 80 m, and has the tendency to increase from the northwest to the southeast of the delta except for three areas with more than 60 m thickness. It serves as the highest groundwater potential. HUA is also widely distributed at a rate of about 88% over the delta, and the aquifer thickness increases from the northwest to the southeast up to more than 60 m. HUA has a high groundwater potential. NWL and MFZ are minor sources for local domestic water supply only. These preliminary findings are worthy to note and can serve as the basis for further groundwater considerations that serves as another beneficial contribution to sustainable water use in the Red River Delta.

Acknowledgements

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