Hydrogeological Framework for Potential Groundwater Resources in Hanoi, Vietnam

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ABSTRACT: Hanoi depends entirely on groundwater for its domestic water supply. However, the characteristics of the entire Hanoi aquifer system remain 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 240 borehole including well logs in order to identify the entire Hanoi hydrogeological framework for potential groundwater resources. Great efforts have been made to establish and analyze hydrogeological maps and 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 with 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 city area. It serves as the highest groundwater potential. HUA is also widely distributed in the south and has a high groundwater potential. NWL and MFZ, placed below PCA but exposed in the north of the city, are minor sources for local domestic water supply only. These findings are indispensable for further groundwater analyses, but have never been completed sufficiently before due to the unavailability of large-scale basic data sets.

1 INTRODUCTION

Sustainable management of groundwater resources is one of the essential objectives for the future of developing countries like Vietnam. Undue groundwater exploitation without the wise management and adequate understanding of the aquifer system has caused some serious problems such as: decline of groundwater level, land subsidence, and groundwater pollution in Hanoi (Tong, 2000; Nguyen and Bui, 2006). Understanding and quantifying groundwater resources is a very complex and difficult task, considerably more problematic and uncertain than surface water hydrology. Although several techniques can assist with hydrogeological interpretations, the most useful and reliable information is observed field data obtained from boreholes.

Researchers in the world have done a great deal of studies aimed at identifying the aquifer system (Zhang et al., 2007; Ludang et al., 2007; McCoy et al., 2007; Mukherjee et al., 2009; Litaor et al., 2008; and, many others). In Vietnam, however, very few original groundwater investigations for the Hanoi area exist in literature. Among these, reseachers investigated on groundwater quality, land subsidence (Nguyen and Helm, 1996; Trinh and Fredlund, 2000). So far, no one has accomplished a comprehensive analysis of the entire Hanoi aquifer system due to the unavailability of basic data, while it is a prerequisite for other studies.

Initiating from these practical difficulties, we recently have implemented a National Hydrogeological Database Project under the nomination of the Department of Geology and Minerals of Vietnam where during the first case, our investigation could put all the basic data together, especially borehole data, from various sources throughout all of Hanoi. These internally-available data

sets include well logs and their hydrogeological properties. To take advantage of our unique data sets as much as possible, the main objectives of this paper are to identify the entire Hanoi hydrogeological framework adequately and quantitatively from the viewpoint of potential groundwater resources. To achieve the aims, this work has focused on acquiring, compiling, and analyzing hydrogeological data from many field sites within the city and from the highest number of existing boreholes, thereby establishing hydrogeological maps and cross-sections. Once these findings are internationally documented, they could provide indispensable fundamentals and serve as basic reference for further hydrological studies in Hanoi.

2 STUDY AREA AND DATA USED

2.1 Study area

Hanoi city is located in the northeast of the Red River Delta plain with the area of around 920 km^2 as shown in Fig. 1. Hanoi has the highest population density in Vietnam. Hanoi's topography has a gradually shifting tendency towards sea level from the North to the South of Hanoi. Most of Hanoi (90%) is flood plain with an elevation of about 10 m above sea level. Hanoi belongs to the tropical monsoonal area with two distinctive rainy and dry seasons in the year. The rainy season lasts from May to October with the rainfall of about 70-80% of the annual rainfall. Evaporation is about 933 mm. The river network is quite dense. The main river is the Red River as shown in Fig. 1. The water of the Red River has a high level of suspended deposits. Due to insufficient infrastructure and unwise management of dumping waste, surface water in Hanoi has been seriously polluted (Tong, 2008). Groundwater thus becomes a main source of water supply in Hanoi. The amount of groundwater abstraction has been rapidly and continuously increasing.

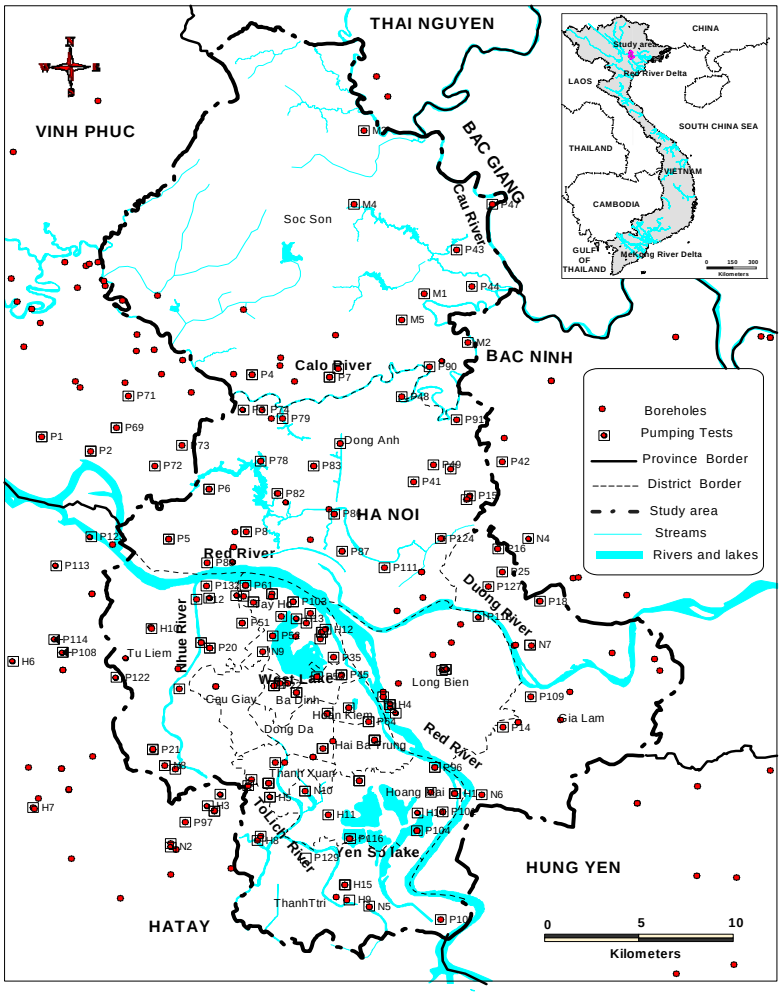

Figure 1, Location of study area and borehole distribution.

2.2 National Hydrogeological Database Project

The reliability and validity of groundwater analysis strongly depend on the availability of data. In Vietnam, however, hydrogeological data are sparse, seldom organized, and accessible to a very limited

number of users. These primary data sets come from various sources and 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. 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 (Tong, 2004).

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

2.3 Data used

To take advantage of the data from our Hydrogeological Database as much as possible, we made best use of all the 240 boreholes and hydrogeological survey data including geological map and their descriptions. These boreholes are classified upon several criterions as summarized in Table 1. This paper focused on analyzing hydrogeological properties, such as: surface boundaries of aquifers, materials, aquifer thicknesses and depths, with the support of GIS in order to characterize the hydrostratigraphical and hydrogeological properties of the entire Hanoi aquifer system from the standpoint of potential groundwater resources.

Table 1, Description of the number of boreholes used (240 boreholes in total).

Location	Within Hanoi	76
	Surroundings	164
Drilled depth	Pleistocene (Quaternary Period)	205
	Neogene (Tertiary Period)	30
	Mesozoic Era	5
Presence of well log	With well log	160
	Without well log	80

3 HYDROGEOLOGICAL FRAMEWORK

In any hydrogeological investigation, the identification of aquifers, aquitards, and the mechanisms of groundwater flow are needed to be properly understood. Knowing a region's hydrogeological framework is fundamental to understand the occurrence and movement of groundwater. Several techniques are used 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. Fig. 2 shows the display of an aquifer system on the surface where HUA is the topmost aquifer and distributes widely from the Red and Duong Rivers to the south of the city with a total area of about 530 km^2 occupying about 55% of the study area. There is a confining layer, aged from Holocene to Pleistocene, named HPA, sandwiched between HUA and PCA. HPA is mostly located under HUA in the south but exposed out on the surface around the center of the Hanoi in the Dong Anh District and the Calo River with a total area of about 25% of Hanoi. PCA is

placed under HUA and HPA. Mesozoic bedrocks exposed on the surface of the ground create mountainous areas with a size of about 120 km^2 in the Soc Son District in the north as shown in Fig. 2. Actually, MFZ, the fractured part of Mesozoic bedrock, is distributed sparsely in small zones of Mesozoic bedrock which is difficult to see in Fig. 2.

Furthermore, we hydro-stratigraphically interpolated strata depth data from a number of well logs. Fig. 3 shows hydrogeological cross-sections demonstrating the hydro-stratigraphy of the aquifer system of Hanoi. Cross-section lines A-A', B-B', C-C' shown in Fig. 2 were selected in the south of the city considering the density of boreholes and the absence of main aquifers in the north. These hydrological cross-sections, A-A', B-B', C-C' were made by interpolating 4, 7, 4 well log data, respectively as shown in Fig. 3. This figure demonstrates a straightforward framework of the aquifer system and hydrogeological conditions in Hanoi. Fig. 3 and other geological information from borehole drilling reports indicated that Hanoi 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.

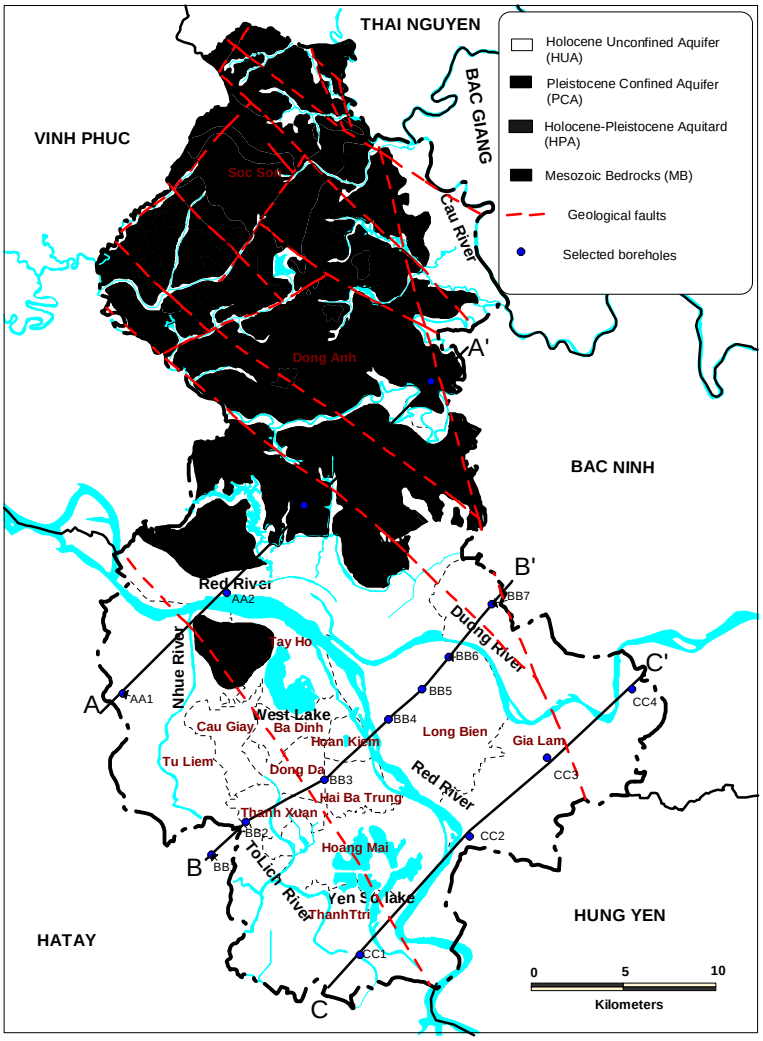

Figure 2, Hydrogeological map of Hanoi city

Geological formations and material ages from the collected well logs and geological description show that Hanoi has a complex geological setting. Quaternary-aged sediments have diversity of strata and lithological materials. The development of Hanoi's geological condition was related to the accommodation, marine transgression and regression, and tectonic activities, so the size 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). The Red River is an important natural recharge source for groundwater storage in Hanoi because it runs across HUA and in some places across PCA due to stream-bed erosion. HPA are mainly composed of silty clay mixing with black-gray plants or clay sand. This aquitard distributes widely over the study area except for some trips along the riverside

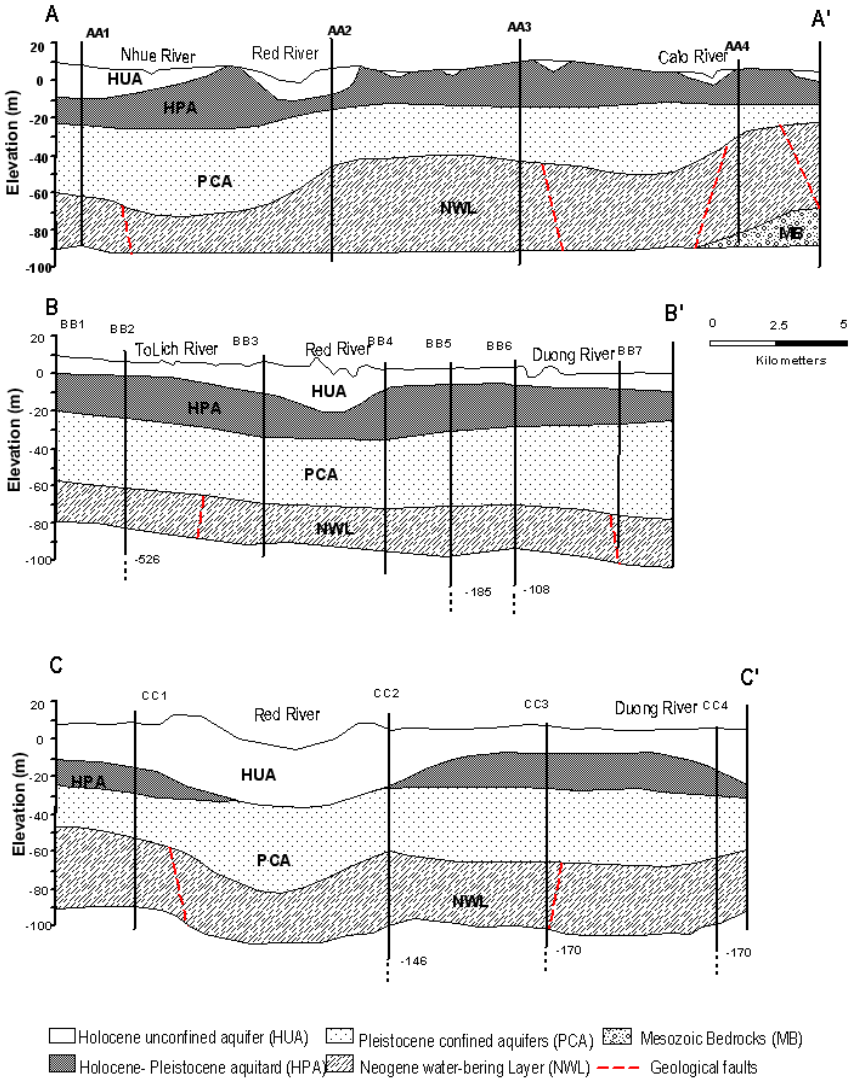

Figure 3, Hydrological cross-sections along A-A', B-B', C-C' lines as shown in Fig. 2.

due to river erosion where the topmost HUA hydraulically connects to the shallow PCA. Thickness of this layer varies greatly, up to 40 m as shown in Fig. 3.

In more detail, the isopach maps of HUA and PCA thickness were drawn using strata data from 160 well logs. The results show that HUA aquifer thickness varies up to more than 35 m with an average of about 15 m. There is a roughly increasing tendency from the north to the south of Hanoi in which there are three areas of more than 30 m thickness. The first one is located in the east of the Yen So Lake. The second one is in the southwest of the West Lake and the last one is in the east of the city along the Duong River. The PCA thickness also fluctuates over a large range, up to 50 m with the average of about 35 m and has an increasing tendency from the north to the south except for three areas of more than 40 m in thickness. The locations of the three areas have quite a similar tendency towards HUA thickness distribution.

4 CONCLUSION

Hanoi depends entirely on groundwater, up to almost 100% for its domestic water supply. In this paper, taking advantage of our recent project on constructing a National Hydrogeological Database, the best

number of 240 boreholes including well logs and their hydrogeological parameters were comprehensively analyzed for the first time in order to identify the aquifer system and characterize hydrogeological conditions in all of Hanoi city from the viewpoint of potential groundwater resources. Hydrogeological data were interpolated and the aquifer system of Hanoi city was identified by creating the hydrogeological map and hydrogeological cross sections. As for the results, Hanoi is composed of Quaternary-aged unconsolidated sediments which consist of HUA, PCA and HPA, directly overlaying the hard formations which form the NWL and MFZ. Also, we focused on analyzing hydrogeological parameters of these water bearing formations, especially HUA and PCA in more detail by making isopach maps of thicknesses. We found that PCA is widely distributed to about 80% in the southern part of the city area. It serves as the highest groundwater potential. HUA is also widely distributed in the south and 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 Hanoi.

5 ACKNOWLEDGMENT

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