Vietnam Journal of Marine Science and Technology; Vol. 21, No. 3; 2021: 299–310
DOI: https://doi.org/10.15625/1859-3097/16431
http://www.vjs.ac.vn/index.php/jmst

Classification of hydrogeological structure along the Red river in the Hanoi area

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Received: 12 October 2020; Accepted: 18 May 2021

Abstract
Hanoi city has abundant groundwater, supplemented by the surface water (mainly Red river) all year round, and the extensive shallow aquifers, which are easily exploited by large-diameter wells. There always exists some open hydrogeological windows in the Red river area with an open structure; therefore, the groundwater has a strained hydraulic relationship with the Red river water system Along the Red river from Ba Vi to the end of Phu Xuyen district, there are nine regions with three types and four sub-types of different hydrogeological structures. In particular, the sub-type I-A of the groundwater has a tight hydraulic correlation with the Red river since the hydrogeological structure of the Red river bottom includes three aquifers: Holocene (qh), upper Pleistocene (qp_2), and lower Pleistocene (qp_1) that constructs a hydraulic system. The sub-type I-B is characterized by the hydrogeological structure at the Red river bottom, including the aquitard in Vinh Phuc and two aquifers qp_2 and qp_1, which form a hydraulic system. The sub-type II-A is distinguished by the fact that the Red river crosses the aquifer qh; there are no aquitards between the aquifer qh and qp_2 to form a hydraulic system; the aquitard separates the aquifer qp_1. The sub-type II-B is identified by the fact that the Red river crossing the aquifer qh; there is an aquitard between the aquifer qh and qp_2; there are no aquitards between the aquifer qp_2 and qp1 so that can create a hydraulic system. Type III has a solid existence of both aquifers and aquitards; thus, the hydraulic relationship between the Red river and the aquifers qp_2 versus qp_1 is inferior.

Keywords: Hydrogeology, hydrogeological structure, groundwater, riverside.

Citation: Trieu Duc Huy, Tong Ngọc Thanh, Nguyen Van Lam, Pham Ba Quyen, Hoang Dai Phuc, Trinh Hoai Thu, 2021. Classification of hydrogeological structure along the Red river in the Hanoi area. *Vietnam Journal of Marine Science and Technology*, *21*(3), 299–310.

INTRODUCTION

Hanoi city exploits about one million cubic meters of groundwater per day for domestic and production purposes [1, 2]. The large-scale exploitation works are mainly gathered inside the aquifer Pleistocene. The intensive exploitation in the southern Red river has led to forming a gigantic lowering groundwater funnel over 300 km^2. Specifically, the long-term exploitation process with high volume and some expanded exploitation works systems cause the lowering groundwater funnel to be reduced and its area to be increased. The groundwater in the distant sites from the Red river and the urban regions is much lowered because the wells' location in some wells fields and the inner city generally has been designed and installed irrationally as their close distances, or the impropriety for the local hydrogeological condition. Besides, the wells located along the riverside, such as Nam Du, Luong Yen, Yen Phu, Cao Dinh, Thuong Cat, etc., are still operated and developed usually thanks to the direct supply from the Red river [3,4,6]. Therefore, the Red river has an essential role in recharging the groundwater. The recharging level is different along the river; it depends on certain factors, in which the hydrological structure is a crucial factor. The hydrological structure's division is vital to the efficient arrangement of the osmotic exploitation works in the riverside [10].

METHODS

We applied a series of methods to identify the hydrogeological structure and determine the spatial relationship between the Red river and the aquifers, as follows:

Identification of the hydrogeological structure

To identify the hydrogeological structure, the authors proceeded with the following steps:

Analyzing the hydrogeological columnar section at the 50 boreholes along the Red river study area.

Constructing 16 hydrogeological cross-sections perpendicular to the Red river and one cross-section along the river's flow direction.

Examining the hydrogeological structure along the Red river concerning its direction of flow. In this step, the analyzers concentrate on clarifying the following information:

The existence of the aquifers and the aquitards

The distribution depth and the thickness of every aquifer and aquitard

Based on the above documents, procedures, and results of 16 hydrogeological cross-sections across the river and along the river, the authors divide the Red river by analyzing the presence of the aquifers and the aquitards in the area into areas with different types and sub-types of hydrogeological structure. In each field, the authors identify the depth of each aquifer and aquitard.

Determination of the spatial relationship between the Red river and the aquifers

To determine the spatial relationship between the Red river and the aquifers based on the documents of hydrogeological and morphological characteristics of the Red river, we proceed with the following steps:

Constructing the topographic cross-sections of the river bed at 95 cross-sections.

Overlapping the river bed topographic cross-sections onto 16 hydrogeological cross-sections.

Analyzing the spatial relationship between the Red river and the aquifers in the study area. In this stage, the analyzers need to concentrate on clarifying the following information:

The aquifers and aquitards are distributed above the river bottom.

The cutting level of the river into the aquifers and aquitards includes the cutting width, cutting depth, cutting area, and the cutting proportion.

The existence of the aquifers and aquitard at the river bottom.

To clarify the hydrogeological structure and the relationship between the groundwater system and the Red river study area, the authors examine the hydrogeological stratigraphy at some boreholes along the river and also evaluate the investigation result of the cross-sections' measurement (95 river cross-sections were implemented by the Red river - Thai Binh Hydrological Survey Team in 2000 [5, 7]). In addition, the authors construct 16

hydrogeological cross-sections across the river and another along the Red river from Ba Vi to Phu Xuyen. Building 16 hydrogeological cross-sections across the Red river is based on the stratification outcome of 259 boreholes in the area were performed through research projects and projects on groundwater from 1993 to the present, especially 50 studied boreholes at 16 cross-sections. The authors observe the morphology of the Red river bottom through the prospection and measurement results of 95 river cross-sections [8, 9]. The position diagram of 16 cross-sections across the Red river in the study area is shown in figure 1.

To build the hydrogeological cross-sections along the Red river from Ba Vi to Phu Xuyen, based on the stratification results at the riverside boreholes, especially at 16 cross-sections, the authors interpolate the layers' depth at the river bottom (the deepest position is on the cross-sections). The Red river bottom's morphology on the longitudinal cross-section is based on the measurement result of 95 cross-sections by observing the deepest position at the river bottom on each measuring line. The hydrogeological cross-section along the Red river in the study area is demonstrated in figure 2.

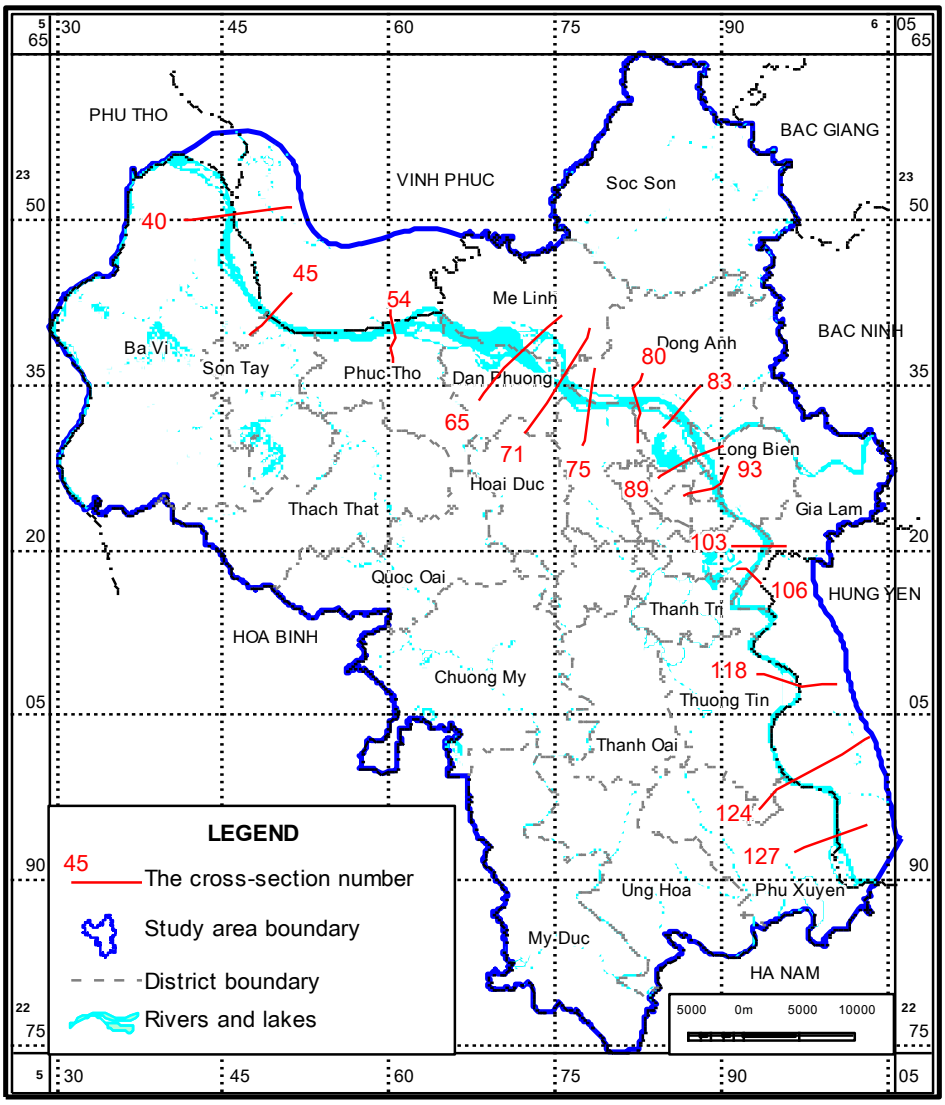

Figure 1. Location of hydrogeological cross-section

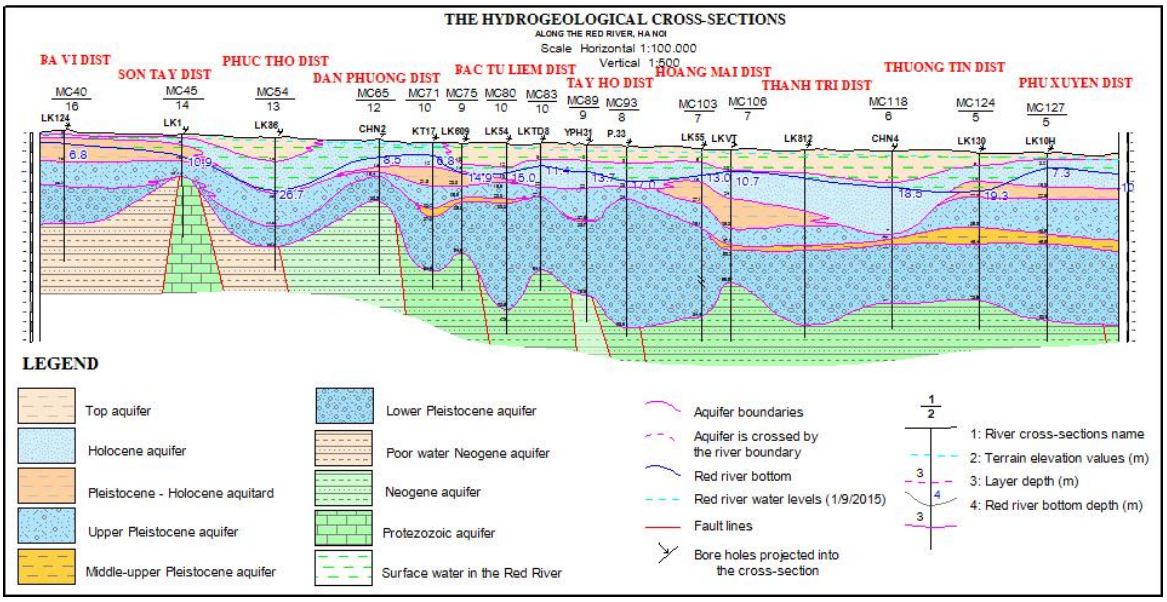

Figure 2. The hydrogeological cross-sections along the Red river in the study area

THE HYDROGEOLOGICAL REGIONALIZATION RESULTS IN THE AREA ALONG THE RED RIVER

The identification at 16 hydrogeological cross-sections across the river and along the river reveals a complete hydrogeological cross-section containing three aquifers and three aquitards in the quaternary sediments (table 1).

The hydrogeological structure analysis leads to a comprehensive presence of the pore-aquifers in the quaternary sediments (qh, qp_2, qp_1) and the discontinuous distribution of the aquitards (layers 1, 3 and 5). The regions from Ba Vi to Son Tay, from Dan Phuong to Bac Tu Liem, from Hoang Mai to Thanh Tri, and Phu Xuyen display the aquifers and aquitards (known as a closed structure). Phuc Tho, Tay Ho, and Thuong Tin present the aquifers thoroughly; however, the aquitard Pleistocene - Holocene (layer 3) is wholly eroded forming hydrogeological windows between two aquifers (known as an open structure). Particularly in the Thuong Tin area, although there is a hydrogeological window between aquifers qh and qp_2, there is an upper middle between the aquifers qp_2 and qp_1 aquitard Pleistocene (layer 4) about 3 m thick, which is distributed continuously. Therefore, the aquifer qp_1 could be considered as a closed structural area.

Table 1. A complete hydrogeological cross-section along the Red river

No.	Layer Sign	Aquifers and Aquitards
1	Layer 1	Weak surface aquitard
2	Layer 2	Pore-aquifer in the Holocene sediments (qh)
3	Layer 3	Aquitard Pleistocene - Holocene
4	Layer 4	Pore-aquifer in the upper Pleistocene sediments (qp_2)
5	Layer 5	Aquitard in the middle-upper Pleistocene
6	Layer 6	Pore-aquifer in the lower Pleistocene sediments (qp_1)

The analyzing result of the spatial relationship between the Red river and aquifers shows that the Red river bottom cuts into almost the aquifer qh but neither the aquifer qp_2

nor qp_1. In many places, there exists a hydrogeological window between the aquifer qh and qp_2, qp_2, and qp_1.

According to the hydrogeological structure analysis and the spatial relationship between the Red river and the aquifers examination, the authors divide the Red river into different structural types and sub-types. In each area, we synthesize and analyze to clarify the following information:

The parameters showing the river bed's characteristics in each area are the river's width (minimum, maximum, average) and the river bottom's depth (minimum, maximum, moderate).

The parameters showing the hydrogeological structure in each area are the aquifers and aquitards' thickness (minimum, maximum, average), the depth of the river bottom cutting into layers (minimum, maximum, intermediate), the width and the area cutting into the middle layer, and the proportion (%) of cutting into layers regarding the cutting area and the cutting depth [11].

By collecting the analyzing results of the hydrogeological structure along the Red river from Ba Vi to Phu Xuyen, the authors divide the study area into nine regions with three structure types (figure 9) as follows:

Type I: including four layers divided into two sub-types, which are sub-type I-A and I-B

Sub-type I-A: including four layers (1, 2, 4 and 6) distributed in two regions (area 2 and 5)

Area 2: From Le Loi, Son Tay town to Tho An, Dan Phuong district with 11.4 km.

Area 5: From Phu Thuong, Tay Ho district to Thanh Luong, Hai Ba Trung district with 13.7 km.

In both areas, the Red river cuts into layer one utterly and layer two partly. At that time, the layers at the river bottom are layers 2, 4 and 6.

A typical hydrogeological cross-section of this sub-type is shown in figure 3.

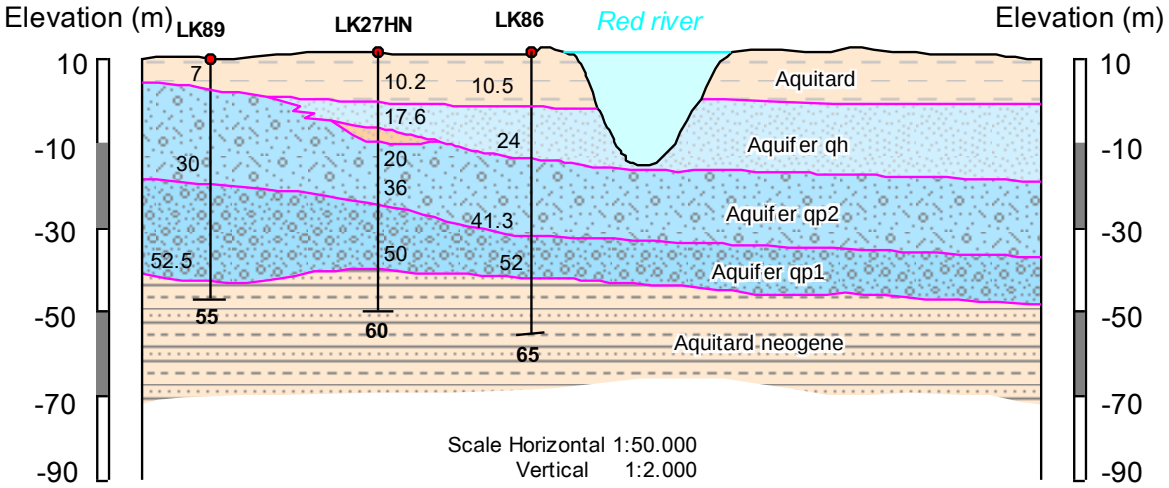

Figure 3. A hydrogeological cross-section of route 54 (Van Phuc - Phuc Tho)

Sub-type I-B: including four layers (2, 3, 4 and 6) distributed in two regions (area 1 and 3)

Area 1: From Phu Cuong, Ba Vi district to Le Loi, Son Tay town with 17.6 km. In this area, the Red river cuts into layer two entirely and layer three partly. At that moment, the layers at the river bottom are layers 3, 4 and 6.

A typical hydrogeological cross-section across the Red river in this area is shown in figure 4.

Area 3: In the areas from Tho An to Lien Hong, Dan Phuong district with 8.4 km, the Red river cuts into layer two partially; meanwhile, the layers at the river bottom are layers 2, 3,4, and 6.

A typical hydrogeological cross-section across the Red river in this area is shown in figure 5.

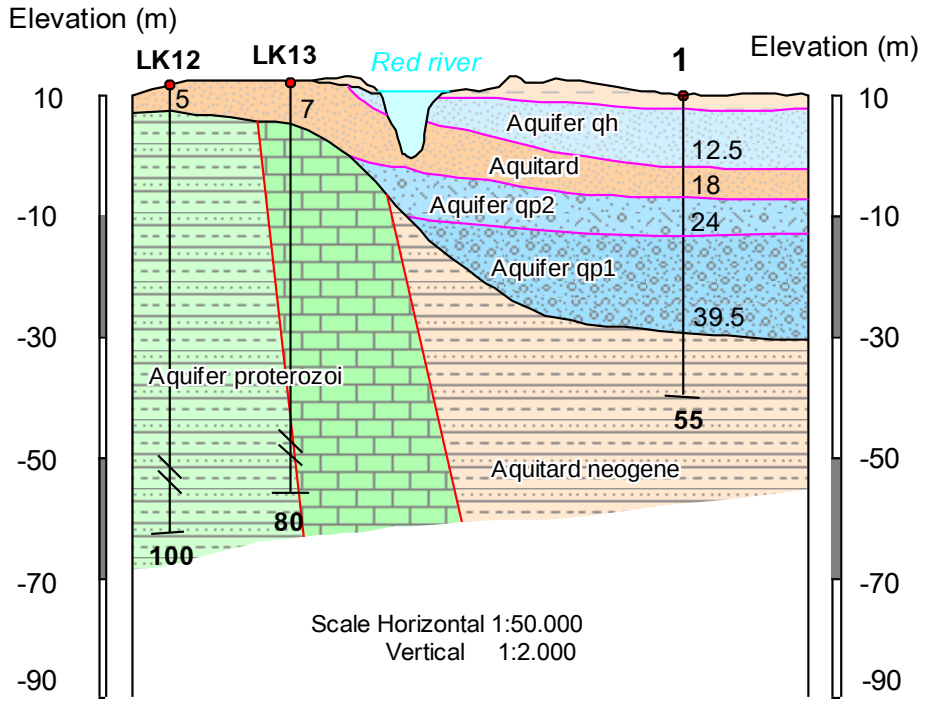

Figure 4. A hydrogeological cross-section of route 45 (Duong Lam - Son Tay)

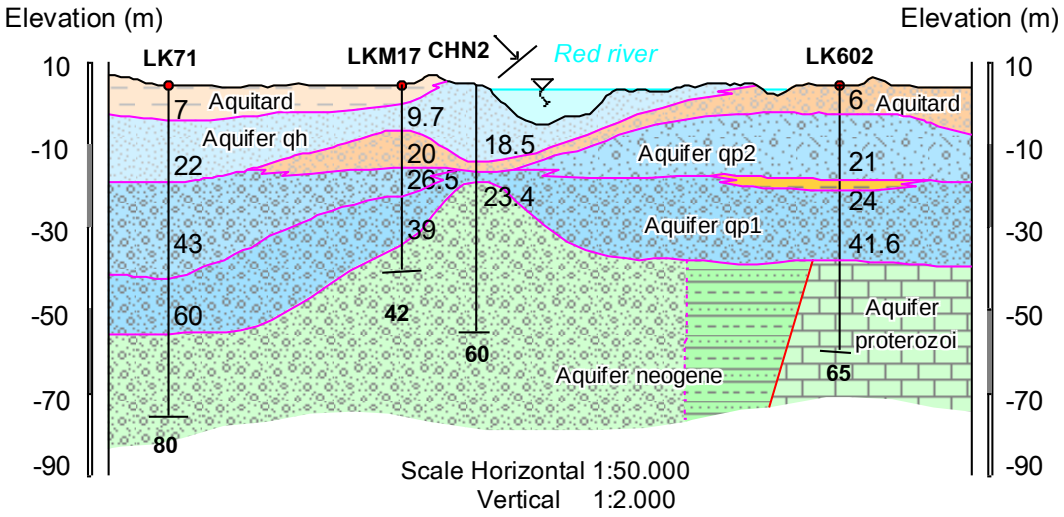

Figure 5. A hydrogeological cross-section of route 65 (Hong Ha - Dan Phuong)

Type II: including five layers divided into two sub-types, which are sub-type II-A and II-B

Sub-type II-A: including five layers (1, 2, 4, 5 and 6) distributed in one region (area 8)

Area 8: In the areas from Hong Van to Le Loi, Thuong Tin district with 9.7 km, the Red river cuts into layer one completely and layer two partly. At the same time, the layers at the river bottom are layers 2, 4, 5, and 6.

A typical hydrogeological cross-section across the Red river in this area is shown in figure 6.

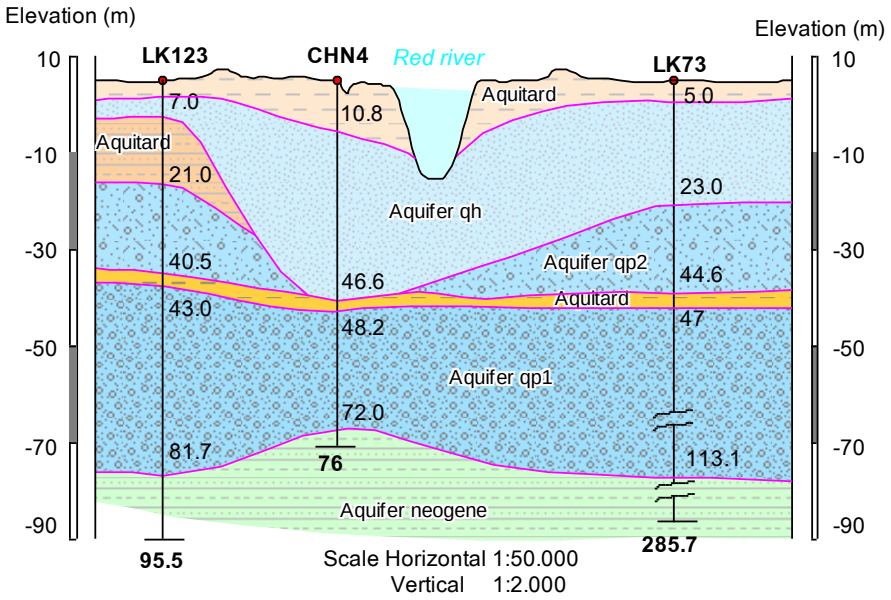

Figure 6. A hydrogeological cross-section of route 118 (Tu Nhien - Thuong Tin)

Sub-type II-B: including 5 layers (1, 2, 3, 4 and 6) distributed in 1 region (area 6)

Area 6: In the areas from Thanh Luong, Hai Ba Trung district to Linh Nam, Hoang Mai district with 9.7 km, the Red river cuts into layer one completely and layer two partly. At the same time, the layers at the river bottom are layers 2, 3, 4, and 6 (figure 7).

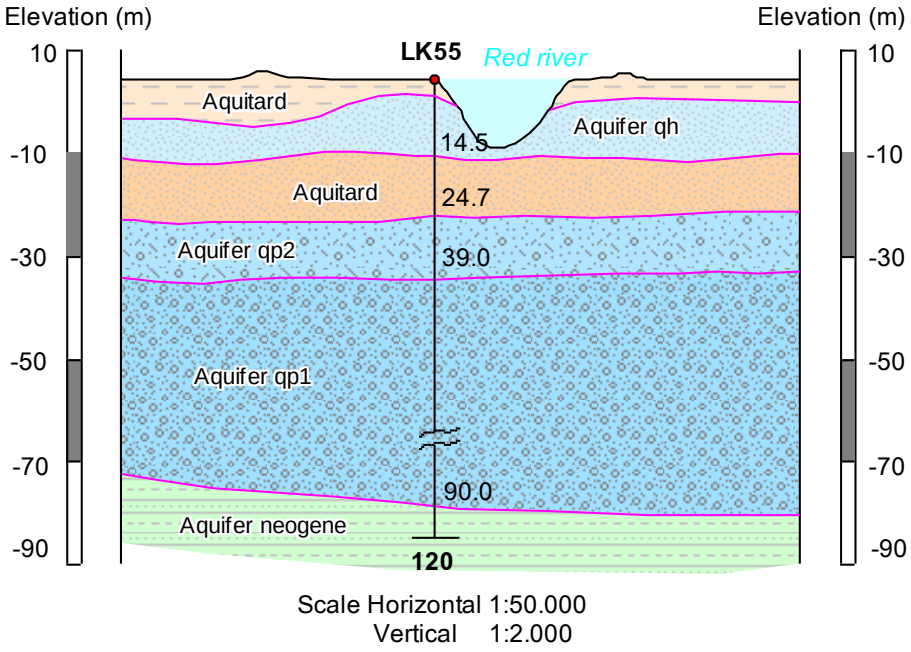

Figure 7. A hydrogeological cross-section of route 103 (Linh Nam - Hoang Mai)

Type III: including 6 layers (1, 2, 3, 4, 5 and 6). This type is not divided into sub-types and is distributed in three regions (area 4, 7 and 9)

Area 4: From Lien Hong, Dan Phuong district to Phu Thuong, Tay Ho district, with 10.6 km long.

Area 7: From Linh Nam, Hoang Mai district to Ninh So, Thuong Tin district, with a length of 13.1 km.

Area 9: From Thong Nhat, Thuong Tin district to Quang Lang, Phu Xuyen district, with a length of 18.2 km.

A typical hydrogeological cross-section across the Red river in this area is shown in figure 8.

In all 3 areas, the Red river cuts into layer 1 totally and layer 2 partly while the layers at the river bottom are layers 2, 3, 4, 5 and 6.

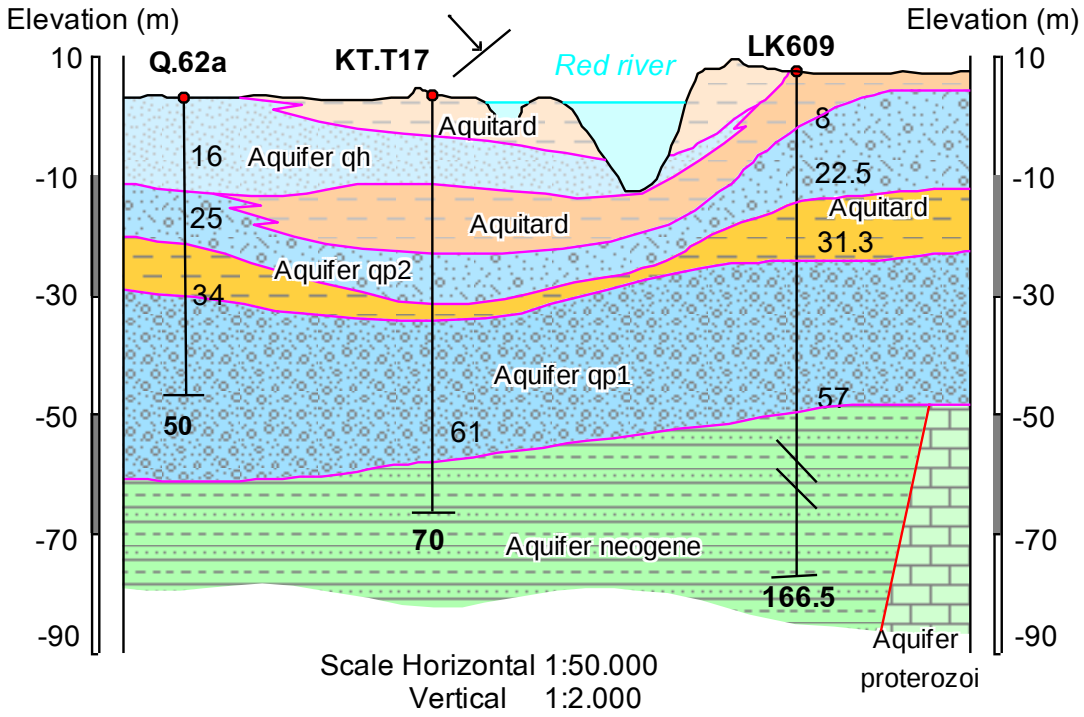

Figure 8. A hydrogeological cross-section of route 75 (Lien Mac - Bac Tu Liem)

Table 2. Synthesis result of the Red river's structural regionalization in the study area

No.	Type	Sub Type	Bottom-river layers relationship area					Layers presence
			2, 4, 6	3, 4, 6	2, 4, 5, 6	2, 3, 4, 6	2, 3, 4, 5, 6	
1	I (4 layers)	I-A	Area 2					Layers 1, 2, 4, 6
			Area 5					
		I-B		Area 1				Layers 2, 3, 4, 6
						Area 3		
2	II (5 layers)	II-A			Area 8			Layers 1, 2, 4, 5, 6
		II-B				Area 6		Layers 1, 2, 3, 4, 6
3	III (6 layers)						Area 4	Layers 1, 2, 3, 4, 5, 6

Table 2 demonstrates the regionalization result of the Red river's structure with different types and sub-types.

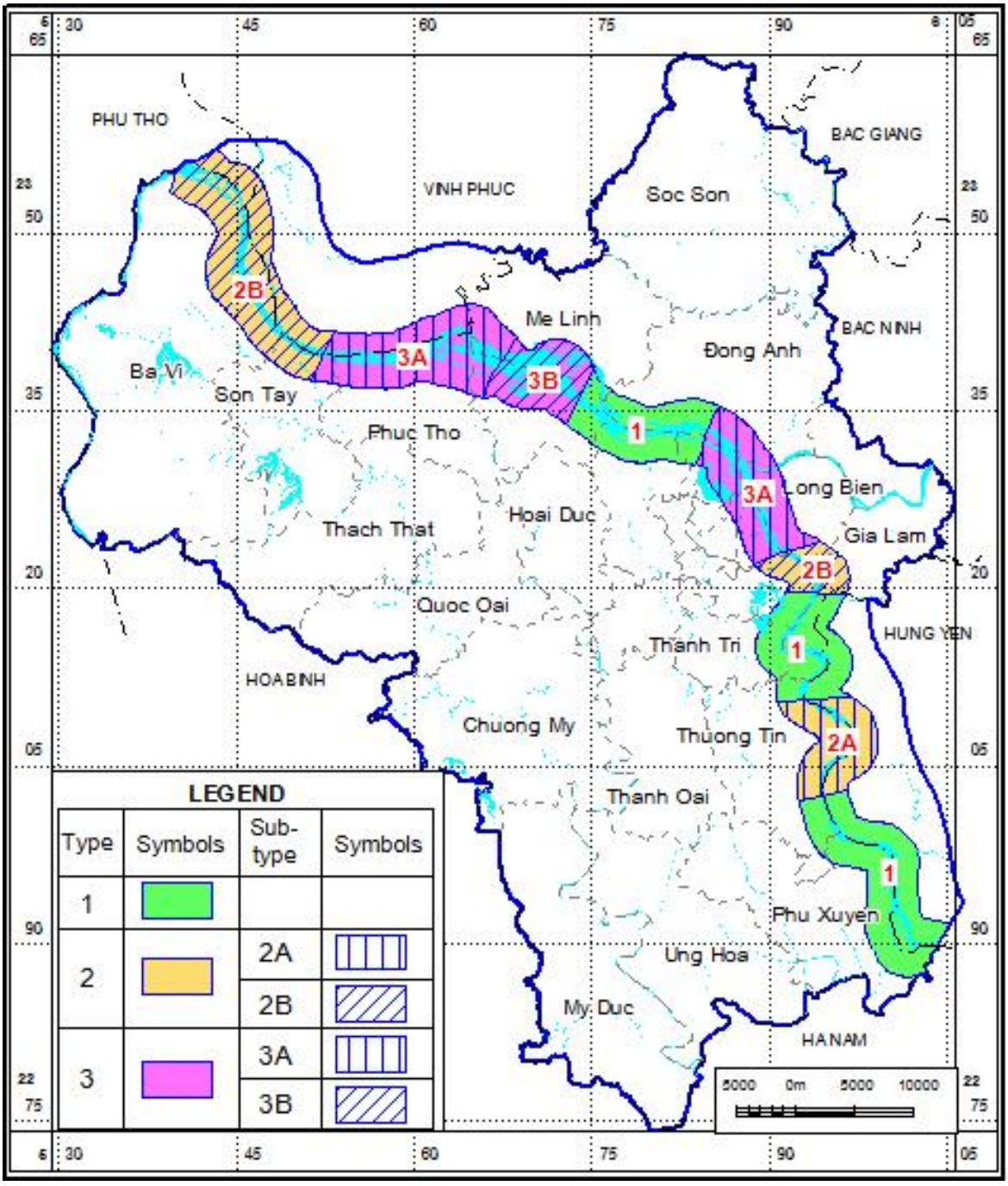

Figure 9. The structural regionalization of the Red river in the study area

The morphological characteristics of the river bed and the layers in each area is synthesized in detail in table 3.

Table 3. Summary of the Red river's characteristic and hydrogeological structure in the study area

No.	Type		Area	Length (km)	Red river bed characteristics						Hydrogeological structure										
					Width (m)			Bottom river depth (m)			Layer	Layers thickness (m)			Cutting into layers depth (m)			Cutting width (m)	Cutting area (m^2)	Cutting proportion (%)	
					min	max	avg	min	max	avg		min	max	avg	min	max	avg			Area	Layers thickness
1	I (4 layers)	I-A	Area 2	11.4	320	1.900	1.110	10.9	26.7	18.8	Layer 2	9	16	12.5	9	14.7	11.9	850	10.073	73%	95%
											Layer 4	10.5	16.8	13.7							
											Layer 6	8.5	10.4	9.5							
			Area 5	13.7	500	1.200	850	11.4	17	14.2	Layer 2	6	14	10.0	3	9	6.0	325	1.950	23%	60%
											Layer 4	4	16.7	10.4							
											Layer 6	37.1	66.9	52.0							
		I-B	Area 1	17.6	400	1.780	1.090	6.8	10.9	8.9	Layer 3	8	12	10	2.8	5.9	4.4	220	957	9%	44%
											Layer 4	8.1	12.4	10.3							
											Layer 6	0	18.6	9.3							
			Area 3	8.4	900	3.100	2.000	8.5	16.5	12.5	Layer 2	12	19	15.5	6	16.5	11.3	1100	12.375	40%	73%
											Layer 3	2.4	8	5.2							
											Layer 4	2	10.5	6.3							
											Layer 6	14.4	29.5	22.0							

2	II (5 layers)	II-A	Area 8	9.7	400	600	500	17	21.5	19.3	Layer 2	15.5	26	20.8	2.5	8.5	5.5	330	1.815	17%	27%
											Layer 4	2.4	10.5	6.5							
											Layer 5	2.6	6	4.3							
											Layer 6	29.3	33	31.2							
		II-B	Area 6	9.7	300	900	600	13	17	15.0	Layer 2	10	12	11.0	7	9	8.0	350	2.800	42%	73%
											Layer 3	5	11.1	8.1							
											Layer 4	9	12	10.5							
											Layer 6	45.3	56	50.7							
3	III (6 layer)		Area 4	10.6	900	1.400	1.150	6.8	15	10.9	Layer 2	4	12	8.0	3	6.8	4.9	420	2.058	22%	61%
											Layer 3	1.9	9.9	5.9							
											Layer 4	6.1	11.3	8.7							
											Layer 5	2.1	4.1	3.1							
											Layer 6	25.6	53.6	39.6							
			Area 7	13.1	400	900	650	10.7	17	13.9	Layer 2	10	23.5	16.8	0.7	7	3.9	95	366	3%	23%
											Layer 3	11.1	15.3	13.2							
											Layer 4	7.8	12	9.9							
											Layer 5	2	3.1	2.6							
											Layer 6	16.3	36.5	26.4							
			Area 9	18.2	400	600	500	7.3	21.5	14.4	Layer 2	8	13.6	10.8	4.1	8	6.1	300	1.815	34%	56%
											Layer 3	6.1	8	7.1							
											Layer 4	14.8	17.6	16.2							
											Layer 5	5	8.6	6.8							
											Layer 6	28.2	38.4	33.3							

CONCLUSION

Hanoi city is favored by nature to receive abundant water resource; besides, the groundwater has a solid hydraulic relationship with the Red river, which provide a regular and stable supply to the groundwater system. The regionalization result of the hydrogeological structure in the Red river Hanoi has a significant meaning in orienting infiltration works construction and determines the Red river's role in supplementing the groundwater in the quaternary sediments.

The results of this study can be used for boundary classification of the Red river in the groundwater flow model to assess and ascertain the river's role in the aquifers in the quaternary sediments in Hanoi.

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