http://doi.org/10.29227/IM-2021-02-05 Received: 25 Jun 2021, Accepted: 25 Sep 2021, Published: 10 Nov 2021

Riverbank Filtration – A Potential Water Source Exploitation for the Red River Delta Region

NGUYEN Trung Hieu[1], DOAN Thu Ha[1,*], HOANG Van Duy[2], TONG Thanh Tung[3]

[1] Thuyloi University, 175 Tay Son, Dong Da, Hanoi, Vietnam

[2] Institute of Water Resources Science, 8 Phao Dai Lang, Dong Da, Hanoi, Vietnam

[3] Division of Northern Water Resources Planning and Investigation, Hanoi, Vietnam

Corresponding author: thuha_ctn@tlu.edu.vn

Abstract. Riverbank filtration technology has been widely applied worldwide because of its high-capacity collection and good water quality throughout natural purification processes. Infiltration water can be extracted from Holocene (qh) layer or the Pleistocene deep layer (qp), replenished with water from the river through hydrogeological windows. Hydrodynamic and isotopic signatures were employed to determine water seepage capacity. The results show that infiltrated water is found in the sand layers along the rivers. However, the seepage rate shows a heterogeneously spatial variation ranging from 30 m^3/d in the Dinh Dao river to 33,600 m^3/d. Km along the shoreline in the Red River (RRD). Also, the exploitation capacity of seepage water differs widely in order of large (> 3,000 m^3/d), medium (1,000-3,000 m^3/d), small (500-1,000 m^3/d), and very small capacity (200-500 m^3/d). This study indicated that RRD could apply riverbank filtration techniques to overcome freshwater scarcity in the delta due to increasing surface pollution and discharge reduction.

Keywords: Seepage water, Hydraulic connection, Hydrogeological window, Red River Delta

1. Introduction

Groundwater in alluvial aquifers is widely used as one of the primary drinking water sources in many countries worldwide because of its high yield and good quality [1]. By pumping wells in an alluvial plain hydraulically connected to a river, it is possible to generate a hydraulic gradient that surface water is forced to flow through the bed and the river banks. During riverbank filtration (RBF) processes, a reduction in the concentration of pollutants is achieved by physical, chemical, and biological processes between the surface water and groundwater and with the substrate [2-5].

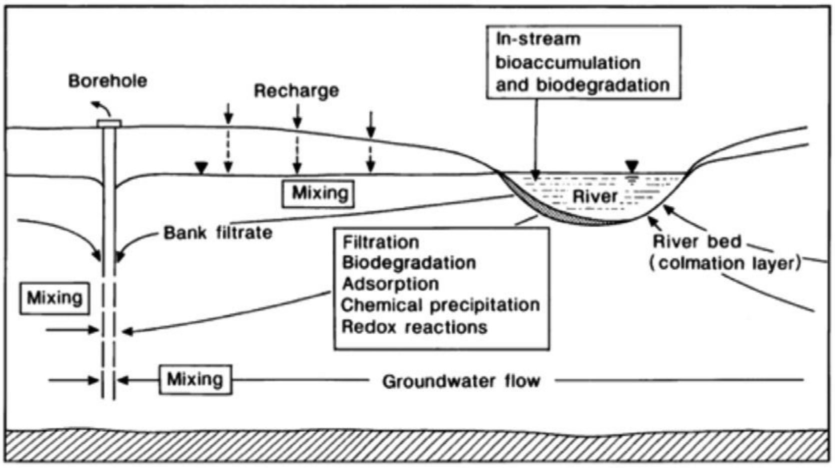

Fig. 1. The basic scheme of riverbank filtration and mail attenuation processes.

The reduction of pollution levels is accomplished by various processes, including physical filtration, microbial degradation, ion exchange, precipitation, sorption, and dilution [6-8]. Other factors that also contribute to the treatment are the river water and the groundwater quality, the porosity of the medium, the water residence time in the aquifer, temperature and pH conditions of water, and oxygen concentrations [9].

In addition to removing pollutants (particles, microorganisms, organic, and inorganic compounds, etc.), there are two additional advantages of RBF. The first is relative to the fact that the flow through the aquifer acts as a barrier against concentration peaks that may result from accidental spills of pollutants. The second is regulating the temperature variations in the river water: during winter, when air temperatures are low, the filtered water is usually warmer than surface water, and in summer, it is more relaxed. The lowest variation in temperature improves the quality and further processing of the bank filtrate [3].

Riverbank filtration technology has been a common practice in Europe for over 100 years, particularly in countries such as Switzerland, where 80% of drinking water comes from RBF wells, 50% in France, 48% in Finland, 40% in Hungary, 16% in Germany, and 7% in the Netherlands [2]. In Germany, for example, 75% of the city of Berlin depends on RBF, whereas in Düsseldorf, RBF has been used since 1870 as the primary drinking water supply [9-10]. On the other hand, in the United States, this technique has been used for nearly half a century, especially in Ohio, Kentucky, Indiana, Illinois, among others [3]. Other countries that have recently started implementing RBF for drinking water supply are India [11], China, and South Korea [12].

Previous studies show a high possibility of a connection between surface and groundwater, especially in the coastal zones of the Red River [13-14]. In addition, some studies have found that surface water is the primary recharge source for the qp aquifer [15-16]. Also, previous studies illustrated that [13-14] showed hydrogeological windows play an essential role in the hydraulic connection between surface water and shallow groundwater in the RRD. Thus, the research on assessing the potential of river infiltration processes for water supply in the Red River Delta region is essential. Some studies used hydrodynamic and isotope methods to evaluate the potential of infiltration water and determine groundwater extraction reserves via RBF processes [17-22]. The RBF can provide an additional water source for domestic and production activities besides the region's surface and groundwater sources.

2. Study area

The RRD is the flat, low-lying plain formed by the Red River and its distributaries merging with the Thai Binh River in northern Vietnam. The region, measuring some 15,000 square kilometers, is well protected by a network of dikes. It is an agriculturally rich and densely populated area. Most of the land is devoted to rice cultivation. Eight provinces together with two municipalities, the capital Hanoi and the port Hai Phong form the delta. It has a population of almost 23 million in 2019. Spanning some 150 km in width, the Red River Delta is located in the western coastal zone of the Gulf of Tonkin. The Red River is the second largest river in Vietnam and one of the five largest rivers on the East Asia coast. Its catchment covers parts of China and Vietnam, and its water and sediment discharge greatly influence the hydrology in the Gulf of Tonkin (Fig. 2).

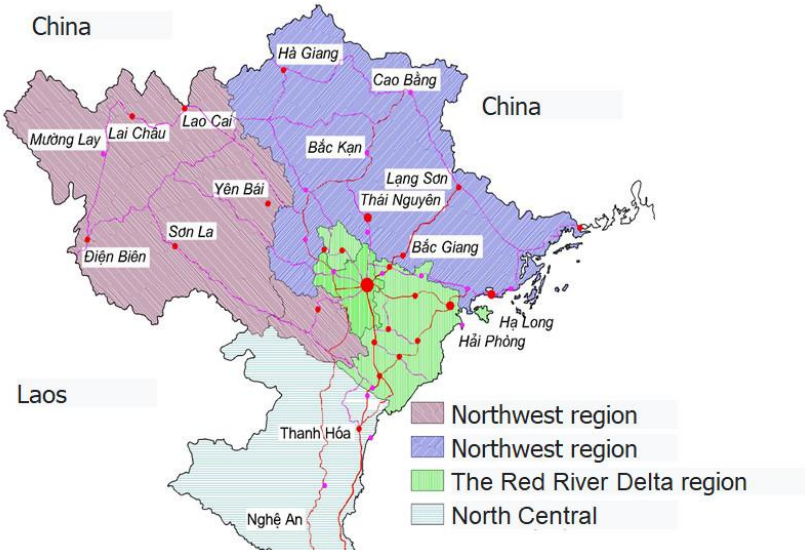

Fig. 2. Position of the Red River Delta region.

The RRD has a flat terrain, slightly declines toward the sea, with dense rivers under the Red -Thai Binh river system. Loose sediments mainly form the delta with a thickness of Quaternary deposit ranging from tens meter in the top and up to 100 m on the sides in the coastal zone. This study considers two aquifers for RBF, including Holocene (q_h) above and Pleistocene (q_p), as shown in Figure 3 below.

http://doi.org/10.29227/IM-2021-02-05 Received: 25 Jun 2021, Accepted: 25 Sep 2021, Published: 10 Nov 2021

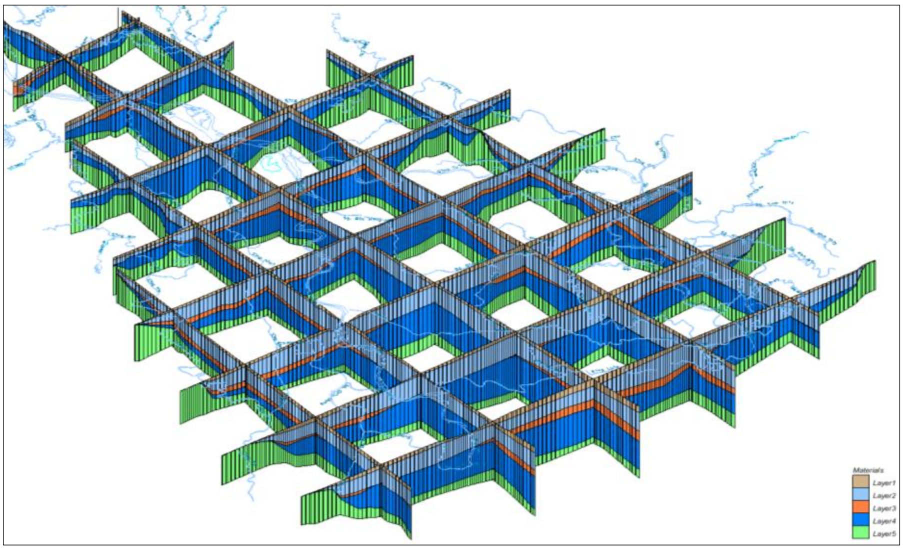

Fig. 3. Hydrogeological structure of the Red River Delta region.

3. Methods

3.1. Estimation of groundwater exploitation

Riverbank infiltration is a complex process; therefore, several issues should be considered, including hydrogeological structure and windows, the hydraulic connection between river surface and groundwater, river replenishment, and groundwater exploitation capacity. Groundwater reserve of a specific region comprises of some components identified according to the following formula:

$$Q_{kt} = Q_{kt} + \frac{V_{dh}}{t} + \frac{\alpha V_{tl}}{t} + Q_{ct} \tag{1}$$

where, Q_{kt} is the exploitation reserve of groundwater (m^3/d); Q_{tn} is the natural dynamic reserve (m^3/d); V_{dh} is elastic static water volume (m^3); V_{tl} is gravity static water volume (m^3); Q_{ct} is entrainment reserve (m^3/d); α is a coefficient infiltrating into gravity static reserve (take like 30% for non-pressure aquifer); t is the calculated exploitation period, typically 104 days.

Among the above-stated components, entrainment reserve (Q_{ct}) happens in the condition of exploitation, including entrainment due to the permeability from the top or from the bottom to the top, entrainment due to the flow from sides, infiltration from surface water sources as rivers, lakes. In favorable conditions, the most considerable entrainment reserve is infiltration from the river.

3.2. Determination of hydraulic connection

In the Red River Delta Region, loose Quaternary sediments are characterized by rhythm distribution; fine-grained formations alternate and interlace coarse-grained ones. The hydrogeological window is a type of hydrogeological structure in which water can penetrate rapidly from the near-surface into deeper aquifers in areas where the continuity of separating low-permeability deposits is disturbed, and their permeability is relatively high. Different aquifers are distinguished in the cross-section, separated by weak water-permeable layers that play a role as water separating layers. The layer separates upper and lowers adjacent layers, creating special hydrogeological features, especially various dynamic hydrogeology. Once the hydrogeological window exists, two aquifers directly overlap, water in the aquifers will interconnect and share the same water level. The hydraulic relationship is the reciprocal interaction between groundwater and river water, either under natural conditions or under human beings intervenes. The study, identification of hydraulic connection is significant to both scientific aspects and problem solutions. The clarification of the hydraulic relationship will contribute to identifying the conditions of dynamic groundwater formation that help assess the groundwater exploitation reserve. Also, it conveys crucial meaning in selecting methods for the construction of coastal infiltration water exploitation works. The hydraulic relationship is studied and identified by: hydrogeological testing, hydrological measurement, monitoring, isotope techniques, hydrogeochemical method, etc.

3.3. Determination of river infiltration water

a) Hydrodynamic Estimation

The method identifying the amount of recharge from the river is based on the permeability resistance in the riverbed and coastal zones, due to deposit of alluvial, bottom sludge which creates a hydraulic resistance and is characterized by the resistance coefficient of sludge layer (A_0), and is identified by the following formula:

$$A_0 = \frac{m_0}{K_0} \tag{2}$$

where K_0 and m_0 is permeability coefficient in vertical direction and thickness of sludge layer on the riverbed.

The volume of infiltration from the river bed is simulated in Figure 4 and identified by the following formula:

$$Q_{cc}^0 = \frac{H_0 - H_1}{A_0} \times 2b \tag{3}$$

where q is the infiltration flow rate from the river (l/s/km); H_0 is the height of river water level (m); H_1 is the height of water level in an aquifer (m); 2b is the river stream's width (m).

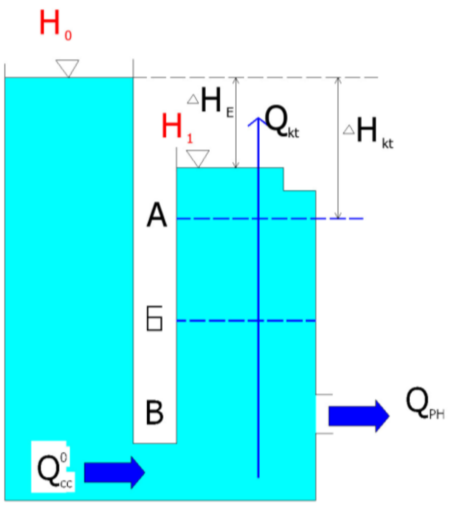

Fig. 4. The diagram on calculating the amount of riverbank infiltration water.

b) Stable isotopes

Based on stable isotope ($\delta^{18}O$) and deuterium ($\delta^2 H$) analyzed data, the infiltration value, and relationships among aquifers are identified in the studied area. The amount of infiltration supply and connection among aquifers are determined based on the following equations:

In the rainy season:

$$\delta^{18}\,\mathrm{O_{nn}} = \mathrm{X_1} \times \delta^{18}\,\mathrm{O_S} + (1 - \mathrm{X_1}) \times \delta^{18}\,\mathrm{O_m} \tag{4}$$

$$\delta^2\,\mathrm{H_{nn}} = \mathrm{Y_1} \times \delta^2\,\mathrm{H}_s + (1 - \mathrm{Y_1}) \times \delta^2\,\mathrm{H}_m \tag{5}$$

In the dry season:

$$\delta^{18}\,\mathrm{O}_s = \mathrm{X_2} \times \delta^{18}\,\mathrm{O_{nn}} + (1 - \mathrm{X_2}) \times \delta^{18}\,\mathrm{O_m} \tag{6}$$

$$\delta^2\,\mathrm{H}_s = \mathrm{Y_2} \times \delta^2\,\mathrm{H}_{nn} + (1 - \mathrm{Y_2}) \times \delta^2\,\mathrm{H}_m \tag{7}$$

http://doi.org/10.29227/IM-2021-02-05 Received: 25 Jun 2021, Accepted: 25 Sep 2021, Published: 10 Nov 2021

From the above equations, X_1, Y_1, and X_2, Y_1 are defined as follows:

$$X_1 = \frac{\delta^{18}\,O_{nn} - \delta^{18}\,O_m}{\delta^{18}\,O_s - \delta^{18}\,O_m} \tag{8}$$

$$Y_1 = \frac{\delta^{2}\,H_{nn} - \delta^{2}\,H_m}{\delta^{2}\,H_s - \delta^{2}\,H_m} \tag{9}$$

$$X_2 = \frac{\delta^{18}\,O_s - \delta^{18}\,O_m}{\delta^{18}\,O_{nn} - \delta^{18}\,O_m} \tag{10}$$

$$Y_2 = \frac{\delta^{2}\,H_s - \delta^{2}\,H_m}{\delta^{2}\,H_{nn} - \delta^{2}\,H_m} \tag{11}$$

where $\delta^{18}O_s$, $\delta^{2}H_s$ are values of isotope oxygen-18 and deuterium in river water (‰) respectively; $\delta^{18}O_m$, $\delta^{2}H_s$ are values of isotope O18 and deuterium in rainwater (‰) respectively; $\delta^{18}O_m$, $\delta^{2}H_{nm}$ are values of isotope oxygen-18 and deuterium in groundwater of Holocene aquifer (‰) respectively; X_1, Y_1 are respective ratios (%) of river water replenished for Holocene aquifer in rainy season calculated according to isotope ($\delta^{18}\,O$) and deuterium ($\delta^{2}\,H$); X_2, Y_2 are respective ratios (%) of groundwater recharged for river water in dry season calculated according to isotope ($\delta^{18}\,O$) and deuterium ($\delta^{2}\,H$).

4. Results and discussion

4.1. Hydrogeological windows

Identifying a hydrogeological window is essential to apply riverbank filtration techniques successfully in the Red River Delta region. In this study area, three types of hydrogeological windows, including river cuts qh aquifer; river cuts qp aquifer; river cuts both qh and qp aquifers.

Hydrogeological window type 1: The river cuts qh aquifer

This hydrogeological window is prevalent in all rivers within the studied area. For 2 regions on the edge of the delta and the Red River from Viet Tri to Hanoi, the river only cuts the upper layer of qh aquifer, the remaining cuts both layers. A typical cross-section of this type is presented in Figure 5.

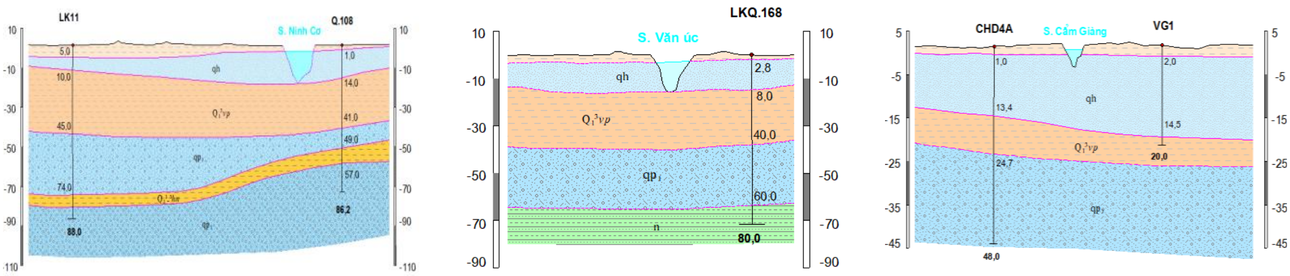

Fig. 5. Hydrogeological section across Ninh Co, Van Uc, and Cam Giang rivers.

Hydrogeological window type 2: The river cuts qp aquifer

This hydrogeological window is typical in the Ca Lo River, Cau river, and rivers on the delta edge. The specific section for this type is displayed in Figure 6.

Hydrogeological window type 3: The river cuts both qh and qp aquifers

This hydrogeological window is popular in Red river, the section from Viet Tri to Nam Du in Vinh Phuc province and Hanoi city, part of Duong river in Dong Anh and Long Bien, Hanoi. The typical section of this type is shown in Figure 7.

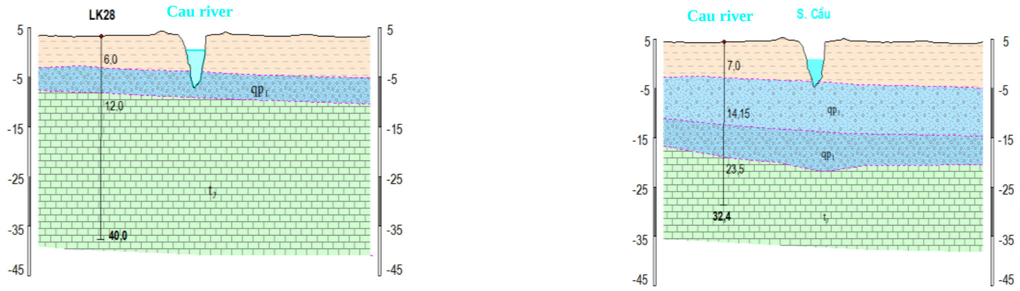

Fig. 6. Hydrogeological section across Ca Lo and Cau rivers.

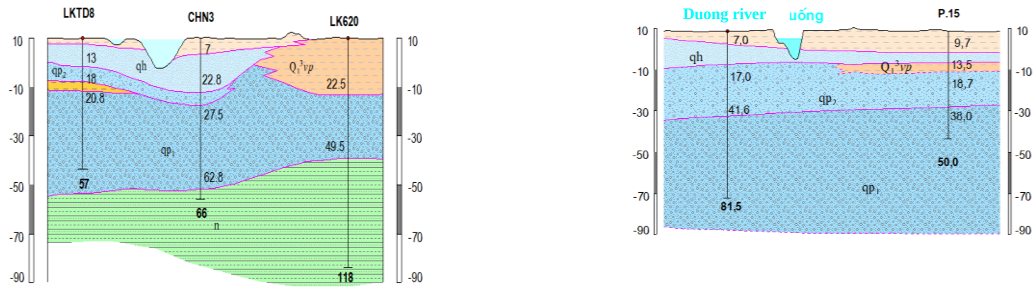

Fig. 7. Hydrogeological section across Red and Duong rivers.

The hydrogeological window described in this type covers the entire Red river bed and extends toward the accretion side at winding sections. The weak infiltration water formations in the upper Vinh Phuc formation are eroded. The river bed directly sits on the qh aquifer, then interconnects to below qp aquifer. This boundary is most clearly identified in Nam Du well field. Of these, 15 drilling wells in the North are located in the winding segments of Red river toward the accretion side in the hydrogeological window where the clay layer separates the qh qp aquifers is absent. Only three wells (H16, H17, H18) in the South have the clay layer separating the qh and qp aquifers.

4.2. Hydraulic relationship between river water and groundwater

The Red River Delta Region covers all four types of hydraulic relationships (Fig. 8) [23-26] with a distribution as follows:

Type 1: Mainly along Red River, the section from Viet Tri to Hanoi, including the beginning section of Duong River. In natural conditions, groundwater plays a vital role in sustaining river flow within the year. However, nearby groundwater river shows a temporal variation, and groundwater is temporarily replenished by river water. Such provision only takes place in the coastal zone where the groundwater flow is directed from the river. The zone's width is from 2 km to 4 km from the edge of river water. If there are any coastal exploitation works, the river water will be provided for those works throughout the year.

Type 2: Mainly in rivers in the center of the delta, typically the South of Cau River, Duong River, where the groundwater is recharged by surface water all around the year. In the flooding period, the replenishment increases and even higher when there are any coastal exploitation works.

Type 3: Popularly in rivers on the delta's edge, typically the North of Cau, Duong, Day, Kinh Thay, and Ca Lo rivers. In these places, groundwater is recharged by river water through the year; however, as the hydraulic decline is not much, the water is still capable of providing for such works when there are exploitation works.

Type 4: Popularly in rivers located in the center of the delta toward the sea. The qp aquifer is deeply situated, and the river does not directly cut the aquifer. The hydraulic relationship still takes place but through separating layers (Fig. 9).

http://doi.org/10.29227/IM-2021-02-05 Received: 25 Jun 2021, Accepted: 25 Sep 2021, Published: 10 Nov 2021

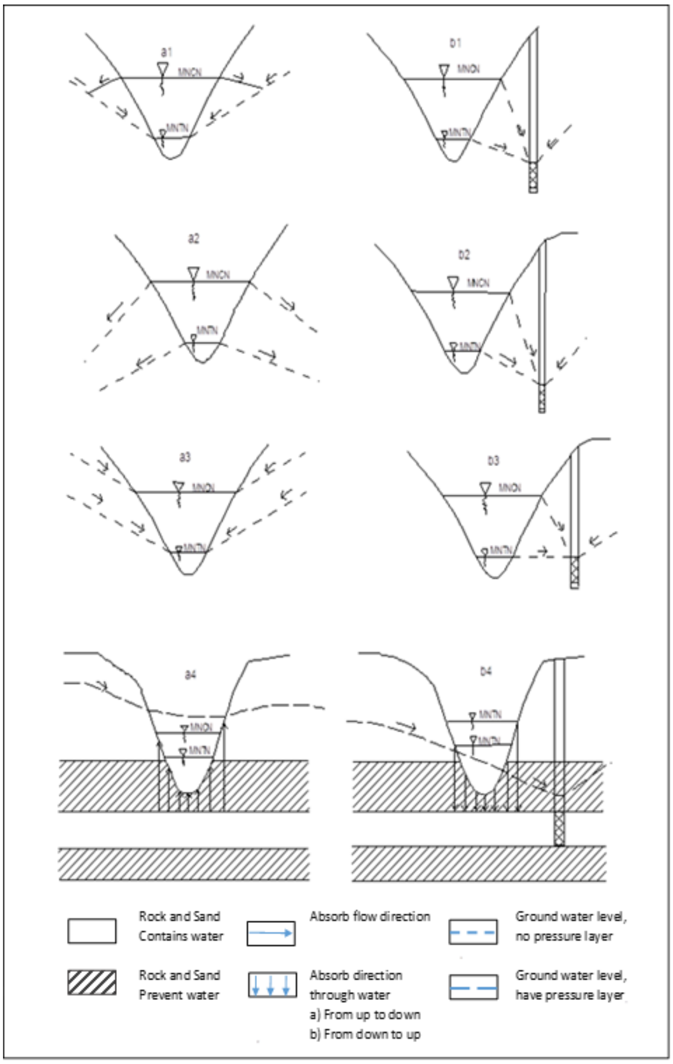

Fig. 8. Types of Surface-groundwater interactions.

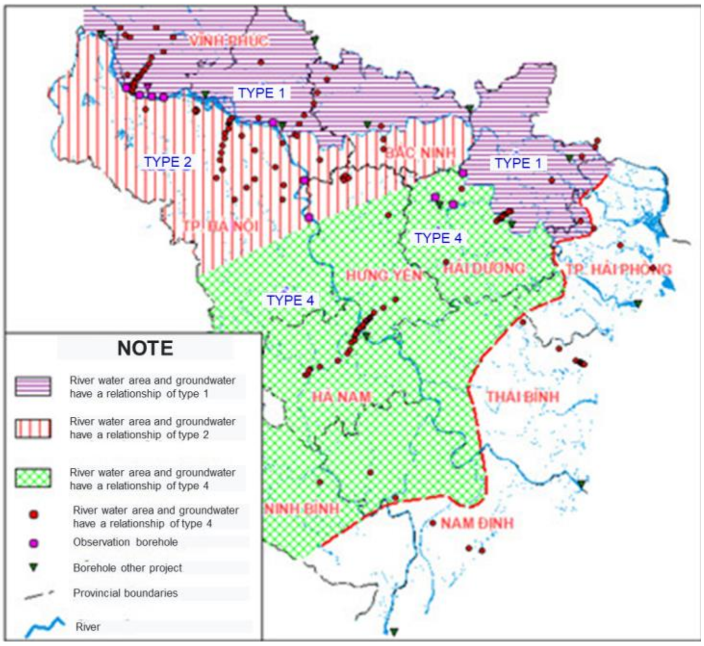

Fig. 9. Zoning Surface-groundwater interactions.

http://doi.org/10.29227/IM-2021-02-05 Received: 25 Jun 2021, Accepted: 25 Sep 2021, Published: 10 Nov 2021

4.3. Amount of permeable water from the river

a) Hydrogeological characteristics

Based on the research results, assessment of water resources implemented [13], the amount of permeable water of studied rivers is calculated, identified, and presented in Table 1.

Tab. 1. Amount of infiltration water of rivers in the Red River Delta Region.

No.	Rivers	Length of river segment (km)	M0 (m)	K0 (m/d)	H0-H1 (m)	2b (m)	Infiltration flow rate (q) (m^3/d/km)
1	Red	183	0.25	0.1	1.8	540	33,600
2	Cau	69	0.15	0.55	0.51	80	12,925
3	Duong	62	0.35	0.25	0.25	180	2,777
4	Rang	25.5	0.55	0.15	0.1	120	282
5	Kinh Mon	0.505	0.25	0.25	0.1	100	864
6	Lach Tray	19	0.25	0.25	0.1	50	432
7	Luoc	70	0.25	0.025	0.1	120	103
8	Ninh Co	33	0.25	0.25	0.1	100	864
9	Thai Binh	74	0.25	0.015	0.1	250	129
10	Cam Giang	3.5	0.25	0.015	0.1	100	52
11	Ke Sat	14.5	0.15	0.015	0.1	180	156
12	Dinh Dao	16	0.15	0.015	0.1	35	30

b) Isotopic Signatures

The study of infiltration water exploitation results within the scientific research project "Research on application and development of riverbank infiltration exploitation technology in Vietnam for living and production activities" [18] define the ratio of river water replenished to groundwater shown in Table 2 and Table 3 below. The statistical results prove that large rivers have a close relationship with groundwater.

Tab. 2. Calculation of recharge amount between river water and groundwater in dry and rainy seasons through stable isotope (^{18}O).

Rivers	Rainy season				Dry season				Notes
	$\delta^{18}O_s$	$\delta^{18}O_{nn}$	$\delta^{18}O_m$	X1	$\delta^{18}O_{nn}$	$\delta^{18}O_s$	$\delta^{18}O_m$	X_2	
Red Segment 1	-6.85	-7.09	-8.48	85%	-6.48	-5.51	-2.9	73%	Ba Vi – Hung Yen
Red Segment 2	-9.86	-8.89	-8.48	30%	-5.95	-5.04	-2.9	70%	Hung Yen – Thai Binh
Cau	-6.99	-7.53	-8.48	63%	-6.78	-4.72	-2.9	46%	
Thai Binh	-10.27	-6.57	-5.15	28%	-7.48	-4.86	-2.9	42%	
Cam Giang	-10.79	-5.96	-5.15	27%	-8	-4.25	-2.9	26%	

Tab. 3. The amount of recharge between the river and groundwater in dry and rainy seasons by stable deuterium isotope (^2H).

Rivers	Rainy season				Dry season				Notes
	$\delta^{18}O_s$	$\delta^{18}O_{nn}$	$\delta^{18}O_m$	X1	$\delta^{18}O_{nn}$	$\delta^{18}O_s$	$\delta^{18}O_m$	X_2	
Red Segment 1	-46.11	-47.73	-55.39	83%	-47.11	-36.12	-9.53	70%	Ba Vi – Hung Yen
Red Segment 2	-63.71	-59.79	-55.39	52%	-34.90	-32.28	-9.53	89%	Hung Yen – Thai Binh
Cau	-42.29	-43.19	-55.39	93%	-43.6	-22.83	-9.53	39%	
Thai Binh	-58.76	-41.98	-35.39	28%	-41.6	-26.56	-9.53	53%	
Cam Giang	-58.39	-40.05	-35.39	20%	-59.24	-24.64	-9.53	30%	

4.3. Determination potential infiltration areas

The potential of water seepage exploitation is determined based on the potential capacity of each infiltration exploitation work. In the RRD, most groundwater extraction works in general and infiltration exploitation, particularly, are drilling wells vertically. According to the actual exploitation results of existing works and results calculating the exploited flow rate of drilling wells in the coastal zone, the areas with potential infiltration exploitation could be divided (Fig. 10).

The area with considerable potential for infiltration exploitation is distributed in the Red River's coastal zone from Viet Tri to Nam Du water treatment plant in Hanoi. The site covers hydrogeological window type 3: Red River cuts both qh and qp aquifers. The hydraulic relationship between surface water and groundwater is of type 1. The Red River's recharge amount is large, the largest among rivers in the Red River Delta Region. The capacity of each well reaches 3,000 m^3/d. In places where there is no bottom sludge, the flow rate could increase sharply. In contrast, the flow rate could decrease enormously in areas where the qp aquifer is thin.

The area with the medium potential of filtration exploitation is distributed in the coastal zone of Ca Lo and Cau rivers, one section at the beginning of Duong and Red rivers from Nam Du well field to Hung Yen. The hydrogeological window in this area is as follows: Cau and Ca Lo rivers cut the qp aquifer, Duong River cuts both qh and qp aquifers, Red River cuts qh aquifer and has a weak hydraulic relationship with qp aquifer. The hydraulic relationship between surface water and groundwater is of type 3 for Cau and Ca Lo rivers, types 2 and 4 for Duong and Red rivers. The recharge amount from these rivers is medium. The capacity of each drilling well reaches from 1,000 m^3/d to 3,000 m^3/d.

The area with a small potential of filtration exploitation is distributed in the coastal Duong River, upper stream of Thai Binh river, and one segment of the Red River from Hung Yen to Nam Dinh. This place exists a hydrogeological window of type 1 that means the river only cuts qh aquifer. The hydraulic relationship between surface water and groundwater is of type 4 with a small recharge from rivers, and the capacity of each drilling well ranges from 500 m^3/d to 1,000 m^3/d.

The area with the minimal potential of filtration exploitation is distributed in the coastal zone of the remaining rivers. This place has hydrogeological window type 1 that means the river only cuts the qh aquifer. The hydraulic relationship between surface water and groundwater is of type 4 with a small recharge, and the capacity of each drilling well fluctuates from 200 m^3/d to 500 m^3/d.

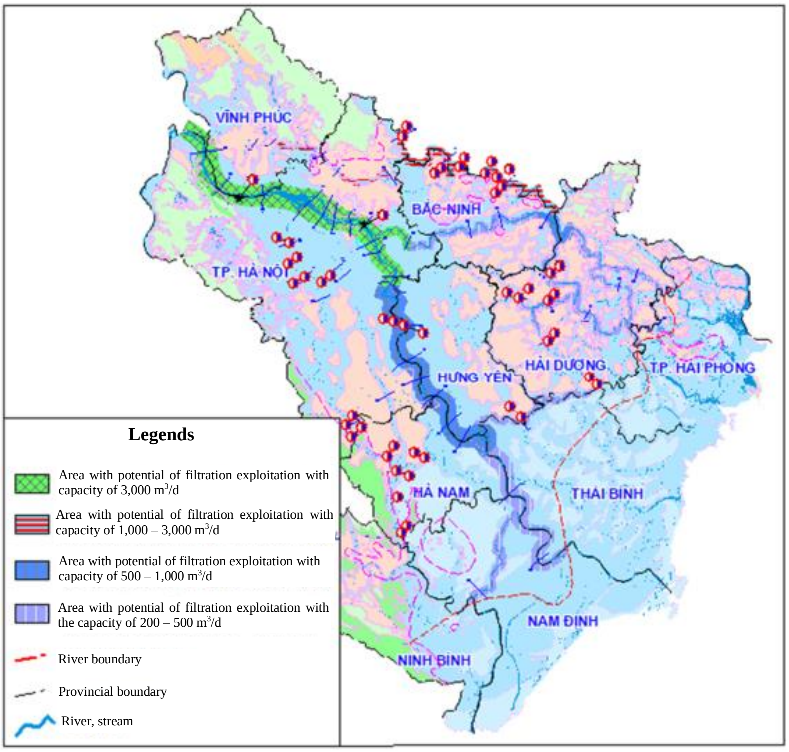

Fig. 10. Zones with potential infiltration water in Red River Delta Region.

5. Conclusion

The study results show that: In the Red River Delta Region, the coastal zone of rivers, there are three types of hydrogeological window: river cuts qh aquifer, qp aquifer, and both qh and qp aquifers. The Red River Delta Region includes four types of hydraulic relationships between groundwater and river water. The river water recharging for groundwater ranges widely from 30 in Dinh Dao river to 33,600 m^3/d.km of the Red River shoreline. The Coastal zone of rivers is divided into 04 areas with various potential of infiltration exploitation: large, medium, small, and very small, equivalent to exploitation capacity of each drilling well: > 3,000 m^3/d, 1,000-3,000 m^3/d, 500-1,000 m^3/d, and 200-500 m^3/d. The studied results present the potential of infiltration water exploitation in the Red River Delta Region and demonstrate a new water source as potential riverbank filtration, or in other words, permeable water, supplying for living activities and rural areas. It plays a vital role, especially under the existing circumstance of exhausted and polluted water sources.

6. Acknowledgments

It was completed within the frame of Research Project under the protocol between the Ministry of Science and Technology Vietnam and The German Federal Ministry of Education and Research, No. 60.GER-19: "Research on application and development of riverbank infiltration exploitation technology in Vietnam for living and production activities".

The paper was presented during the 6th VIET - POL International Conference on Scientific-Research Cooperation between Vietnam and Poland, 10-14.11.2021, HUMG, Hanoi, Vietnam.

7. References

1. Doussan, C., Ledoux, E. and Detay, M., 1998. River- groundwater exchanges, bank filtration, and groundwater quality: Ammonium Behavior, Journal of Environmental Quality, 27(6), 1418-1427, https://doi.org/10.2134/jeq1998.00472425002700060019x.
2. Tufenkji, N., Ryan, J. N. and Elimelech, M., 2002. The promise of bank filtration, Environmental Science and Technology, 36(21): 422A-428A, https://doi.org/10.1021/es022441j.
3. Hiscock, K.M. and Grischek, T., 2002. Attenuation of groundwater pollution by bank filtration, Journal of Hydrology, 266(3-4): 139–144,https://doi.org/10.1016/S0022-1694(02)00158-0.
4. Matusiak, M., et al., 2021. Surface water and groundwater interaction at long-term exploited riverbank filtration site based on groundwater flow modelling (Mosina-Krajkowo, Poland), Journal of Hydrology: Regional Studies. 37: 100882, https://doi.org/10.1016/j.ejrh.2021.100882.
5. Covatti, G. and T. Grischek, 2021. Sources and behavior of ammonium during riverbank filtration, Water Research, 191: 116788, https://doi.org/10.1016/j.watres.2020.116788.
6. Lee, W., et al., 2020. Spatiotemporal evolution of iron and sulfate concentrations during riverbank filtration: Field observations and reactive transport modeling, Journal of Contaminant Hydrology, 234: 103697, https://doi.org/10.1016/j.jconhyd.2020.103697.
7. Kondor, A.C., et al., 2020. Occurrence of pharmaceuticals in the Danube and drinking water wells: Efficiency of river bank filtration, Environmental Pollution, 265: 114893, https://doi.org/10.1016/j.envpol.2020.114893.
8. Ray, C., Grischek, T., Schubert, J., Wang, J.Z. and Speth, T.F., 2002. A perspective of riverbank filtration, Journal of American Water Works Association (AWWA), 94(4): 149-160, https://doi.org/10.1002/j.1551-8833.2002.tb09459.x.
9. Kuehn, W. and Mueller, U., 2000. Riverbank filtration: an overview, Journal of American Water Works Association (AWWA), 92(12): 60-69.
10. https://doi.org/10.1002/j.1551-8833.2000.tb09071.x.
11. Schubert, J., 2002. Hydraulic aspects of river bank filtration - field studies. Journal of Hydrology, 266: 145 - 161, https://doi.org/10.1016/S0022-1694(02)00159-2.
12. Sandhu, C., Grischek, T., Kumar, P. and Ray, C., 2010. Potential for riverbank filtration in India, Clean Techn Environ Policy, pp. 1-22 (DOI 10.1007/s10098-010-0298-0).
13. Ray, C., 2008. Worldwide potential of riverbank filtration, Clean Technologies and Environmental Policy, 10: 223-225, DOI: 10.1007/s10098-008-0164-5.
14. Lan, N.M., 2014. Research on the relationship between river water and ground water, proposal of method system for determining exploitation reserve of groundwater in coastal Red River from Son Tay commune to Hung Yen, Archives of Department of Water Resources Management, Hanoi.
15. Dan, N.V., 2010 Ground water resource in Hanoi city region and orientation for research, investigation, exploitation for use, Proceedings of International Science Conference on 1,000th Anniversary of Thang Long, 1007–1016.
16. Quyen, P.B., 2015. Report on investigation and assessment of water resources in the Hanoi Capital region, Archives of Department of Water Resources Management, Hanoi.
17. Minh, T., 1993. Report on ground water exploration in the Greater Hanoi. Archives of Geology, Hanoi.
18. General Department of Geology and Minerals of Vietnam., 1979. Report on groundwater exploitation in Bai Bang area, Lam Thao, Phu Tho province. Archives of Geology, Hanoi.
19. Dan, N.V., 2012. Possibility of construction of groundwater exploitation well fields with large capacity provided to Hanoi Capital, Meteorology and Hydrology Journal, 620: 1–5.

20. Ha, D.T., 2020. Report on research result of the project "Research on application and development of riverbank infiltration exploitation technology in Vietnam for living and production activities". Scientific research project No. 60.GER–19, Ministry of Science and Technology).
21. Pholkern, K., Srisuk, K., Grischek, T., Soares, M., Schäfer, S., Archwichai, L., Saraphirom, P., Pavelic, P., Wirojanagud, W., 2015. Riverbed clogging experiments at potential river bank filtration sites along the Ping River, Chiang Mai, Thailand. Environ. Earth Sci. 73: 7699–7709.
22. Wang, Y., Zheng, C., Ma, R., 2018. Review: Safe and sustainable groundwater supply in China, Hydrogeol. J., 26: 1301–1324, https://doi.org/10.1007/s10040-018-1795-1.
23. Wassenaar, L.I., Ahmad, M., Aggarwal, P., Van Duren, M., Pöltenstein, L., Araguas, L., & Kurttas, T., 2012. Worldwide proficiency test for routine analysis of δ^2H and $\delta^{18}O$ in water by isotope-ratio mass spectrometry and laser absorption spectroscop, Rapid Commun Mass Spectrom, 26(15):1641-1648. https://doi.org/10.1002/rcm.6270.
24. Dan, N.V., Thanh, T.N., 2000. The characteristics of the formation of groundwater dynamics in the QII-III aquifer of the Northern Delta region and the significance of water supply, Geology Journal, Hanoi.
25. Dan, N.V, Thanh, T.N. and Huy. T.D, 2002. On the possibility of building absorbent works along the Red River, Geological Journal No. 44 Series A.
26. Dan, N.V., Thanh, T.N, 2000. The characteristics of the formation of groundwater dynamics in the QII-III aquifer of the Northern Delta region and the significance of water supply, Geology Journal, Hanoi.