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Evaluation of Interaction between Surface Water and Groundwater in the South of Hanoi City by Stable Isotope Technique

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Abstract

The $\delta^{18}O$ and $\delta^{2}H$ stable isotope techniques for studying properties of groundwater and surface help us to understand more clearly about the distribution and movement of groundwater in the South of Hanoi area. There were 68 water samples from the studying area and analyzed by a Liquid Water Isotope Analyzer (LWIA-24D). The stable isotope values of the groundwater from Pleistocene aquifers were range from −3.21‰ to −9.55‰ $\delta^{18}O$ and −35.32‰ to −67.44‰ $\delta^{2}H$; rainwater from −8.18‰ to −4.13‰ $\delta^{18}O$ and −61.19‰ to −17.93‰ $\delta^{2}H$; Red river water from −7.51‰ to −5.29‰ $\delta^{18}O$ and −51.60‰ to −38.99‰ $\delta^{2}H$. Based on stable isotope characteristics, the results show that there was a relationship between surface water and groundwater in the South of Hanoi city. It is that groundwater recharges for river water in the dry season with 74%, and in the rainfall season groundwater is recharged from river with 87%.

Keywords

Stable Isotopes, Groundwater, Surface Water, River Water, Precipitation, Recharge

1. Introduction

The surface water and the groundwater are important components of water cycle, and the interaction between the surface water and the groundwater is the important part in water cycle research [1]. Evaluation of the interactions between surface water and groundwater is crucial for guaranteeing water supply quality in a riverside water source area [2].

Hanoi Capital is located in the Northern Delta centre and the cultural center of the country. So that the population density in here is very high and the demand for clean water is extremely large. The Red River Delta is the largest population concentration in the country with 22.5 million people depends on groundwater from the delta area as their main water source [3]. The groundwater resources in Hanoi city include 3 main aquifers: Holocene aquifer (qh), Pleistocene aquifer (qp) and Neogene aquifer (n). According to the Department of Water Resources Management, forecast data for total water resources for aquifers is: Holocene aquifer (qh) is 976,204 m^3/day; Pleistocene aquifer (qp) is 7,199,313 m^3/day [4]. In which, the Pleistocene aquifer is the main source supply in the Hanoi city. Therefore, problems about water quality security and control for human activities are essential [4] [5] [6].

Environmental isotope technology is a modern technology with the development of nucleus science since the 1950s and 1960s, and lots of successful studies have been carried out in water cycle research. The main applications of environmental isotope technology in water cycle research are to trace water cycle, determine sources and components of the surface water and groundwater flow and separate water sources [1] [7]. The isotope techniques used early for mixture researching between surface water and groundwater [7] [8]. Now, these techniques are used extensively and effectively in research and evaluation of the groundwater recharging [9] and contamination investigations of groundwater [10] [11]. The stable hydrogen and oxygen isotope ratios can be valuable tools for investigating hydrologic systems [12] [13]. Because they are a part of the water molecule itself [8]. Researching teams were studied the interaction between surface water and groundwater by the δ^{18}O and δ^2H stable isotope techniques [8] [14] [15] [16]. The researchers defined status of mixed groundwater and surface water recharges. When the groundwater mixes with the surface water, they impact their characteristics upon one another [9] [10].

So that the main targets of this study was to evaluate the interaction between surface water and groundwater in the South of Hanoi capital by using ^{18}O and δ^2H stable isotopic and to determine whether or not this interaction changes over time.

2. Study Area

The study area is in the South of Hanoi Capital, include four districts: Hai Ba Trung, Thanh Tri, Hoang Mai, Thanh Xuan; lying between North latitudes 20˚56'13"N to 21˚05'415"N and East Longitudes 105˚45'07"E to 105˚55'15"E. **Figure 1** shows the geographical location of the Hanoi South.

In terms of topography, the study area is located in the Red River Delta (also known as North Delta) where mainly consists river alluvial Delta. In terms of geomorphology, the study area deeply reflects tropical inner climatic quality (the monsoon tropics). The study area in northern Vietnam is internal climate monsoon tropics in terms of climate [17].

The average annual temperature is range from 22˚C to 25˚C per year. The total annual precipitation is about 1500 mm within the rainy season accounts 80% to 85% of annual precipitation. The geological section is divided into four parts according to lithology composition. The hydro-geological section includes two main aquifers such as Holocene aquifer, Pleistocene aquifer and Neogene aquifer [18] [19].

The study carried out sampling of rainwater (RW), Red River water (RRW) and groundwater (GW) in the study area and determined the stable isotopes $\delta^{18}O$ and $\delta^{2}H$ to evaluate the interactions between Red river water and groundwater of the Pleistocene aquifer.

3. Sampling and Analytical Method

Sampling Procedures

There were six major sampling campaigns to be carried out in two years from 2015 to 2016 and 2020 to 2021 including the dry season and the rainy season in 2015 and 2016, the rainy season in 2020 and the dry season in 2021. The RRW and RW samples at Long Bien Hydrological Stations are collected monthly. Sample information is presented in **Table 1**.

The pH, electrical conductivity (EC) values should immediately measure at sampling locations with IAEA documents [20].

Sampling procedures and preservation for the $\delta^{18}O$ and $\delta^{2}H$ stable isotope analysis: Fill a 50 mL, double capped, glass or polyethylene bottle directly from the source or from a secondary container. During sampling, storage and transportation to the laboratory take care to avoid evaporation of the sample. Polyethylene or glass bottles with 1 L volume were suitable for tritium sampling collection [21].

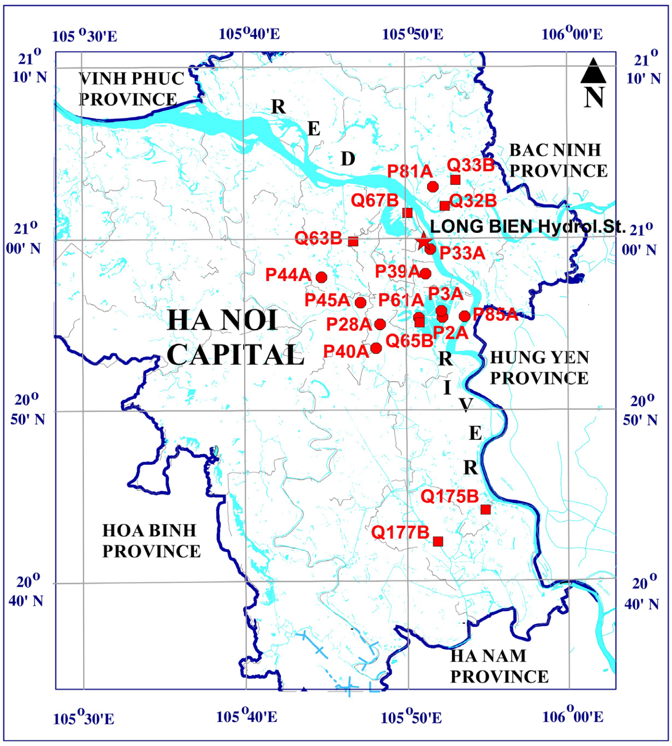

Figure 1. Sampling location map of the Hanoi South.

Table 1. The location and sampling date of water samples.

ID sample	Sample type	Latitude (N)	Long (E)	Time	
				Dry season	Rainy season
P28A	Ground Water (GW)	20˚57'29.95"	105˚48'23.89"	Mar in 2015 and 2016	Aug in 2015 and 2016
P2A		20˚57'54.71"	105˚52'15.23"		
P33A		21˚1'52.13"	105˚51'32.41"		
P39A		21˚0'26.33"	105˚51'13.63"		
P3A		20˚58'16.36"	105˚52'10.86"		
P44A		21˚0'16.11"	105˚44'47.43"		
P45A		20˚58'47.15"	105˚47'11.26"		
P61A		20˚57'52.03"	105˚50'47.12"		
P81A		21˚5'30.71"	105˚51'42.70"		
P85A		20˚57'56.59"	105˚53'37.80"		
Q32b		21˚4'23.98"	105˚52'26.57"	Mar in 2021	Aug in 2020
Q33b		21˚5'55.72"	105˚53'6.83"E		
Q63b		21˚2'22.04"	105˚46'45.50"		
Q65b		20˚57'35.32"	105˚50'50.60"		
Q67b		21˚3'60"	105˚50'8"		
Q175b		20˚46'38.50"	105˚54'50.53"		
Q177b		20˚44'47.36"	105˚51'53.52"		
RRW	Red River	21˚2'31.42"	105˚51'32.53"	Mar in 2015, 2016 and 2021	Aug in 2015, 2016 and 2020
RW	Precipitation	21˚2'31.42"	105˚51'32.53"		

Analytical methods

The determination of the $\delta^{18}O$ and $\delta^{2}H$ stable isotope compositions in water samples are carried out on the LWIA-24D Laser mass spectrometer (Liquid Water Isotopes Analyzer) in Isotopes Hydrology laboratory, Institute for Nuclear Science and Technology, 179 Hoang Quoc Viet Street, Vietnam.

Procedures of the $\delta^{18}O$ and $\delta^{2}H$ stable isotopes analysis in water samples comply with the IAEA standard operating procedure for the liquid water isotopes analyzer published in 2009 with a uncertainty <0.1‰ for $\delta^{18}O$ and <0.3‰ for $\delta^{2}H$ [22].

Electrical conductivity, pH are measured in the field with Seven Multil handheld.

4. Results and Discussion

4.1. Field Parameters

The pH, temperature, EC and precipitation results: The pH values in boreholes are range from 6.46 to 8.17 and the RRW samples are range from 6.37 to 8.79 which suitable for the Vietnam National Standards such as QCVN 08:2008/

BTNMT [23] (National technical regulation on surface water quality) for the surface water and QCVN 09:2008/BTNMT [24] (National technical regulation on underground water quality) for the GW. The temperatures of water samples are changed by seasonal characteristics. The temperature of water samples in the dry season is range from 24.3˚C to 32.3˚C and from 19.4˚C to 28.6˚C in the rainy season; the average temperature was 25.2˚C in 2015, 2016, 2020 and 2021. Total rainfall is 1681 mm in 2015, 1632 mm in 2016, 1626 mm in 2020 and 1792 mm in 2021. Figure 2 depicts seasonal variation of the precipitation and temperature in Hanoi from 2015 to 2016 and 2020 to 2021. EC electrical conductivity results are range from 103 to 1335 μSv/cm in GW samples and from the 98.3 to 1140 μSv/cm in RRW samples.

4.2. Isotopic Compositions of Water Samples

The results of isotopic compositions of the GW, RRW and RW which collected from 2015 to 2016 and 2020 to 2021 were displayed in the Table 2.

Isotopic compositions

The results shown that the stable isotope compositions of the Pleistocene aquifer were from −3.21‰ to −9.55‰ for δ^{18}O and −35.32‰ to −66.54‰ for δ^{2}H; mean results of RRW were −5.37‰ and 7.46 ‰ for δ^{18}O, −39.11‰ and −50.38‰ for δ^{2}H in dry and rain season from 20215 to 2016, respectively; mean results of RW were −4.16‰ and −8.13 ‰ for δ^{18}O, −18.69‰ and −57.55‰ for δ^{2}H in dry and rain season from 2015 to 2016 respectively. The mean results of RW and RRW from 2020 to 2021 were −7.65‰ δ^{18}O and −49.44‰ for δ^{2}H, −9.53 δ^{18}O and −67.44‰ for δ^{2}H, respectively.

Set up the LMWL and RRWL

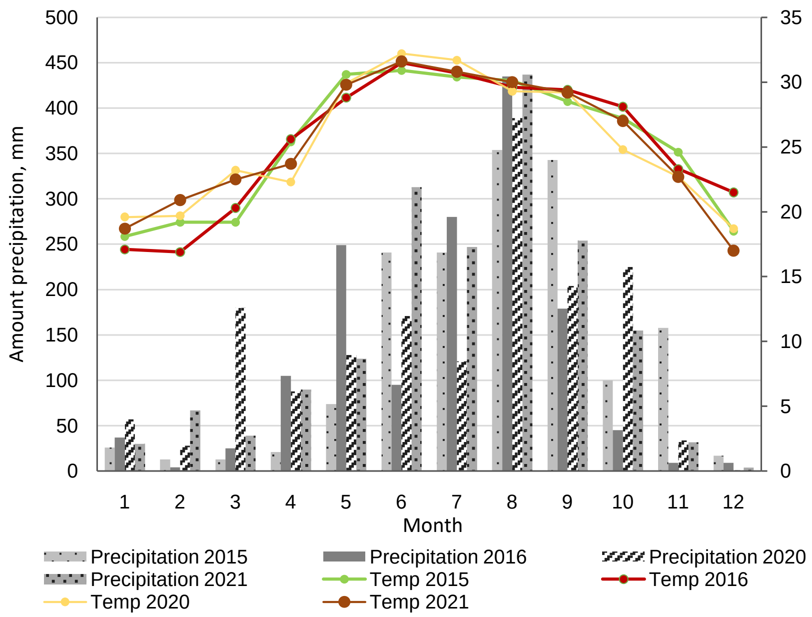

Figure 2. A comparison of seasonal charges of the precipitation and temperature in Hanoi from 2015 to 2016 and 2020 to 2021.

Table 2. The stable isotopic compositions of GW, RRW and RW which collected from 2015 to 2016 and 2020 to 2021.

Time	**2015**				**2016**			
	Dry season		**Rainy season**		**Dry season**		**Rainy season**	
Borehole	**$\delta^{18}O$**	**$\delta^{2}H$**	**$\delta^{18}O$**	**$\delta^{2}H$**	**$\delta^{18}O$**	**$\delta^{2}H$**	**$\delta^{18}O$**	**$\delta^{2}H$**
					‰			
P33a	−8.67	−60.21	−8.69	−59.63	−5.93	−49.37	−8.49	−58.5
P81a	−7.59	−50.78	−8.67	−59.71	−6.09	−50.33	−6.91	−48.80
P85a	−7.73	−55.73	−8.75	−59.69	−6.87	−45.11	−8.86	−54.73
P40a	−4.51	−38.56	−6.75	−48.53	−5.02	−42.02	−6.71	−42.5
P39a	−5.41	−48.70	−5.59	−38.63	−5.67	−45.02	−6.83	−46.20
P45a	−5.08	−39.81	−7.98	−52.81	−4.85	−42.72	−6.43	−49.23
P28a	−5.41	−48.70	−7.21	−48.50	−5.09	−50.33	−8.50	−57.10
P2a	−4.91	−42.78	−6.16	−39.97	−6.12	−47.21	−6.93	−45.93
P3a	−3.21	−35.32	−6.58	−49.15	−6.90	−45.15	−8.58	−56.09
P61a	−4.51	−36.65	−9.55	−66.54	−6.54	−47.88	−6.81	−44.22
Average	**−5.70**	**−45.72**	**−7.59**	**−52.32**	**−5.91**	**−46.51**	**−7.51**	**−50.33**
RRW	−5.29	−38.99	−7.51	−51.60	−5.46	−39.22	−7.41	−49.16
RPW	−4.18	−19.15	−8.18	−58.15	−4.13	−18.22	−8.08	−56.95
Time	**2020**				**2021**			
Q175b			−7.52	−51.12	−5.85	−45.38		
Q177b			−6.52	−47.56	−6.62	−48.12		
Q32b			−7.13	−42.45	−5.67	−45.44		
Q33b			−7.18	−50.28	−5.60	−42.87		
Q63b			−6.54	−54.4	−4.98	−43.11		
Q65b			−8.12	−54.87	−5.02	−42.21		
Q67b			−9.54	−67.44	−6.70	−52.98		
Average			**−7.51**	**−52.59**	**−5.78**	**−45.73**		
RRW			−7.43	−51.25	−5.38	−38.99		
RPW			−8.12	−61.19	−4.23	−17.93		

The stable isotope compositions in RW and RRW in Northern Vietnam have been determined continuously for a period of 10 years from 2001 to the end of 2011 with sampling frequency once a month, in accordance with the Guidelines of IAEA. As a result, the local meteorological water line (LMWL) in the Northern Delta region and the Red River water line (RRWL) in Hanoi area have been built. The LMWL and the RRWL in the Northern Delta region follow the model: $\delta^{2}H = 8.04 \times \delta^{18}O + 12.96$ ($R^2 = 0.99$) and $\delta^{2}H = 5.51 \times \delta^{18}O - 10.90$ ($R^2 = 0.79$), respectively [25].

Assessment of groundwater genesis

Figure 3 and Figure 4 depict the relationship between $\delta^{18}O$ and $\delta^{2}H$ stable isotopes compositions of the GW Pleistocene aquifers in Hanoi from 2015 to 2016 and 2020 to 2021. In which, the GW in the dry season was represented by the blue line ($\delta^2H = 4.07 \times \delta^{18}O - 22.42$ and $R^2 = 0.71$) in the **Figure 3** and in the rainy season was represented by the black line ($\delta^2H = 6.30 \times \delta^{18}O - 3.83$ and $R^2 = 0.70$) in the **Figure 4**.

In the dry season, the stable isotope values of Pleistocene aquifer boreholes were represented by the blue line (GWL). So, the RRW was located between the LMWL and the GWL in the **Figure 3**. It shows that the Pleistocene aquifer boreholes in the dry season recharged to the RRW. But the rainy season, the stable isotope values of Pleistocene aquifer boreholes were represented by the black line which lies between the RRWL and LMWL in **Figure 4**. It shown that Pleistocene aquifer in the rainy season was supplied by two main water sources such as RRW and RW.

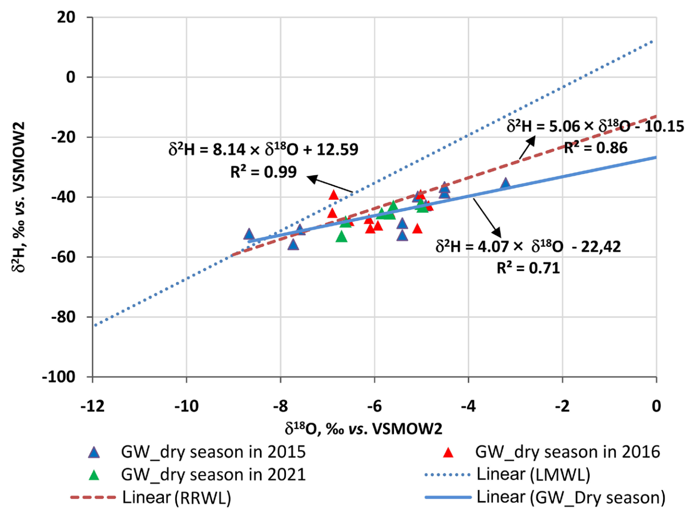

Figure 3. The $\delta^{18}O$ and δ^2H values of the RW, RRW and GW from 2015 to 2016 and 2020 to 2021 in dry season.

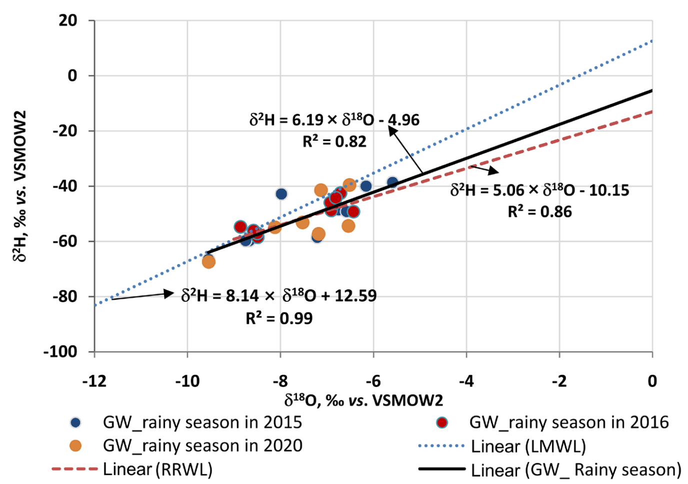

Figure 4. The $\delta^{18}O$ and δ^2H values of the RW, RRW and GW from 2015 to 2016 and 2020 to 2021 in rainy season.

Assuming groundwater origins are mixed by RW and the river water. So the isotopic composition in GW also shows the contribution of RW and the river water isotopic components with different ratios. The equation can be used to assess recharged contributions of the river water to the GW in the rainy season [7]:

$$X = \frac{\delta gr - \delta p}{\delta r - \delta p} \times 100\% \quad (1)$$

And the equation can be used to assess recharged contributions of the GW to the river in the dry season [7]:

$$Y = \frac{\delta r - \delta p}{\delta gr - \delta p} \times 100\% \quad (2)$$

where δgr, δr, δp are the stable isotopic compositions of hydro (or oxygen) of the GW, river water and precipitation water, respectively.

Based on characteristics of the stable isotopic compositions, there is a natural interaction between the aquifers and the Red River, where leakage happens under pristine conditions during the dry season from aquifers into the Red River. During the rainy season, river water normally infiltrates into the aquifers [26]. **Table 3** and **Table 4** present the results using the $\delta^{18}O$ and δ^2H stable isotopic compositions of calculating the river water recharged for aquifers in the rainy season and the Red River was recharged by aquifers in the dry season, respectively. The results in the **Table 3** & **Table 4** showed no difference in using $\delta^{18}O$ and δ^2H isotope composition to determine the water rechargeable process. RRW recharged 87% average for GW in the rainy season and was recharged 74% average by the Pleistocene aquifer in the dry season. Comparison of the above calculation results with the previous results of other researchers shows that it is perfectly suitable with the results of identification of recharged sources for aquifers in the Red riverside area [27] [28] [29].

Table 3. Value of the stable isotope composition ($\delta^{18}O$) and results of recharging calculation.

Rainy season in 2015			**Dry season in 2015**		
$\delta^{18}O_{RRW}$	$\delta^{18}O_{GW}$	$\delta^{18}O_{RW}$	$\delta^{18}O_{RRW}$	$\delta^{18}O_{GW}$	$\delta^{18}O_{RW}$
−7.51‰	−7.59‰	−8.18‰	−5.29‰	−5.70‰	−4.18‰
	X = 88%			Y = 73%	
Rainy season in 2016			**Dry season in 2015**		
$\delta^{18}O_{RRW}$	$\delta^{18}O_{GW}$	$\delta^{18}O_{RW}$	$\delta^{18}O_{RRW}$	$\delta^{18}O_{GW}$	$\delta^{18}O_{RW}$
−7.41‰	−7.51‰	−8.07‰	−5.46‰	−5.91‰	−4.13‰
	X = 86%			Y = 75%	
Rainy season in 2020			**Dry season in 2021**		
$\delta^{18}O_{RRW}$	$\delta^{18}O_{GW}$	$\delta^{18}O_{RW}$	$\delta^{18}O_{RRW}$	$\delta^{18}O_{GW}$	$\delta^{18}O_{RW}$
−7.43‰	−7.51‰	−8.12‰	−5.38‰	−5.78‰	−4.23‰
	X = 89%			Y = 74%	

Table 4. Value of the stable isotope composition (δ^2H) and results of recharging calculation.

Rainy season in 2015			Dry season in 2015		
δ^2H_{RRW}	δ^2H_{GW}	δ^2H_{RW}	δ^2H_{RRW}	δ^2H_{GW}	δ^2H_{RW}
−51.60‰	−52.32‰	−58.15‰	−38.99‰	−45.72‰	−19.15‰
	X = 89%			Y = 75%	
Rainy season in 2016			**Dry season in 2015**		
δ^2H_{RRW}	δ^2H_{GW}	δ^2H_{RW}	δ^2H_{RRW}	δ^2H_{GW}	δ^2H_{RW}
−49.16‰	−50.33‰	−56.95‰	−39.22‰	−46.51‰	−18.22‰
	X = 85%			Y = 74%	
Rainy season in 2020			**Dry season in 2021**		
δ^2H_{RRW}	δ^2H_{GW}	δ^2H_{RW}	δ^2H_{RRW}	δ^2H_{GW}	δ^2H_{RW}
−51.25‰	−52.59‰	−61.19‰	−38.99‰	−45.73‰	−17.93‰
	X = 87%			Y = 76%	

The results of recharging calculation (Table 3 and Table 4) between RRW and GW in 4 years from 2015 to 2016 and 2020 2021 shown that, there were not big changes by season and year. As is known, the variation of the $\delta^{18}O$ and δ^2H stable isotopic compositions in RW and RRWs often corresponds to the main changes of temperature, precipitation and also runoff [7] [13]. And there was no significant difference in the temperature of the months and the amount precipitation in the year (Figure 2). This is suitable for the results in Table 3 & Table 4. It was shown that the stable isotope values in RRW, RW and the average value of GW at the same time of year have very little difference. That explains why there was not much difference in the results of recharging calculation in the four years.

5. Conclusion

The Pleistocene aquifer GW in the Southern area of Hanoi has a hydraulic interaction relationship with the RRW. Research results using stable isotope techniques show that in the rainy season, the GW is recharged 87% of the water volume by RRW. Meanwhile, the RRW is recharged 74% of the water volume by GW in the dry season. During the 4-year study period, the research results on the interaction between the GW and the RRW did not have much difference, indicating that the aquatic environment is stable and sustainable. This study shows that the management of local water resources is appropriate. The using GW for living and economic development of the capital has not caused any serious problems for the living environment in recent years.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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