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Use of isotope techniques to evaluate the recharged ability of the upper Pleistocene aquifer in the Nambo Plain

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Abstract: In the Nambo Plain, the monitoring data on dynamics and quality of groundwater has shown declining signs in quantity and quality both in the existing groundwater aquifers, and the exploitation of groundwater in recent time is believed to be a cause of this decline. That shows the need for further research, especially on the modern recharge ability of the existing groundwater aquifers, to re-evaluate the groundwater potential of the region. For that purpose, isotope techniques are applied to evaluate the recharge ability of the upper Pleistocene aquifer, an important source of water supply in rural areas in the Nambo Plain.

In this study, groundwater, river water and rainwater samples were collected and analyzed for stable isotope composition, tritium, radiocarbon and major hydro-chemical parameters. Data on stable isotope composition in groundwater are used to define the origin of groundwater while tritium and ^{14}C content are used to determine groundwater age and to predict the aquifer's recharge zone; and in combination with the stable isotope composition and tritium content of river water to evaluate the dynamic relationship between river water and groundwater.

The obtained results show that: i) Groundwater in the study aquifer is originated from meteoric water and formed at different stages. ii) The high ^{3}H and ^{14}C content in some groundwater samples indicate that the aquifer has modern rainwater infiltrated as a recharge source. iii) The similarity of stable isotope composition in the Vam Co river water and groundwater adjacent to the river shows that there is a hydraulic relationship between them. This is an important basis for assessing the recharge ability to the qp_3 aquifer of the Vam Co river water.

Keywords: *Groundwater, qp_3 aquifer, Isotopic composition, ^{2}H, ^{18}O, ^{3}H, ^{14}C, Nambo Plain.*

I. INTRODUCTION

Groundwater (GW) is a very important natural resources for most countries in the world and in some areas GW accounts for nearly all usable freshwater. Therefore, it is very important to assess the capacity of GW in order to use and better manage GW resources, especially in Vietnam.

In many areas of Vietnam, including Nambo Plain, water used for production and daily activities is taken from surface water and GW sources, of which GW becomes the main source due to the limitation of surface water with global climate change and human activities. The monitoring data on dynamics and quality of GW has shown declining signs both in quantity and quality in the existing GW aquifers, and the exploitation of GW in recent times is believed to be a cause of this decline. That shows the need for further research, especially on the modern recharge ability of the

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existing GW aquifers to re-evaluate the GW potential for the sustainable utilization and management of GW resources in the region.

According to the previous GW study results by isotope techniques, the Pliocene aquifers in the area are recharged by modern rainwater and the shallow aquifer is recharged by surface water from Saigon River, Dongnai River and Dautieng lake [1-4]. In this study, isotope techniques are applied to evaluate the recharge ability of the upper Pleistocene aquifer (qp_3), an important source of water supply in rural areas in the Nambo Plain.

The suitable isotopes including ^{2}H (D or Deuterium), ^{18}O, ^{3}H (tritium), ^{14}C, ^{13}C are used in this study. ^{18}O and ^{2}H are used to identify the origin of GW and evaluate the hydraulic relationship between river water and GW. ^{3}H, ^{14}C and ^{13}C are used for determining the age, flow direction, flow rate of GW; GW recharge zone by rainwater [1, 5 - 9].

II. STUDY AREA

Located in the southernmost part of Vietnam, Nambo Plain is one of the most important economic regions with a total area of around 54000 km^2 and more than 40 million people. As a tropical monsoon region, the climate in the Nambo Plain is dominated by monsoons with intense sunlight, high temperature and there are two seasons. The rainy season lasts from May to October with warm moist tropical winds from the southwest. The dry season usually begins in November and ends in April with cooler and drier winds from the northeast. The annual average rainfall is usually about 1800 mm with more than 90% in the rainy season and the mean temperature is about 27^{o}C.

The Nambo Plain has formally divided into two regions apart: the Southeast region (Dong Nambo) is mainly basalt and old alluvium and the Southwest region (Tay Nambo) is young alluvium [10]. This Plain is a relatively flat area with topographical gradients from the north and northeast to the south and southeast that control the direction of GW flow in the area.

There are three main river systems in Nambo Plain: the Mekong River system, the Vam Co River system and the Saigon-Dongnai River system and the dense network of canals. All of them are the chief contributors of freshwater to the region, the largest of which is Mekong River system which annually discharges a total of about 500 km^3 of freshwater into the Nambo Plain through Tien River and Hau River. The previous studying data show the possibility of recharge from rainwater and river water in Nambo Plain [10].

Hydrogeological settings

The Paleozoic and Mesozoic formations in Nambo Plain are opened in the north and northeast region and closed in the southeast region form a tectonic graben, which is filled with a succession of sediment deposits from Paleocene to Holocene marked by general marine regressions-transgressions in south-east Asia. This sedimentary sequence contains various aquiferous horizons separated by imperious layers [10].

According to the latest hydro-geological identification [11], there are 8 GW aquifers in the Nambo Plain, namely, the Holocene aquifer (qh), the Upper Pleistocene aquifer (qp_3), the Middle Pleistocene aquifer (qp_{2-3}), the Lower Pleistocene aquifer (qp_1), the Upper Pliocene aquifer (n_2^2), the Lower Pliocene aquifer (n_2^1), the Upper Miocene aquifer (n_1^3) and the Water in basement (Mz) as shown in the northeast-southwest hydrogeological cross-section of the Nambo Plain in Figure 1.

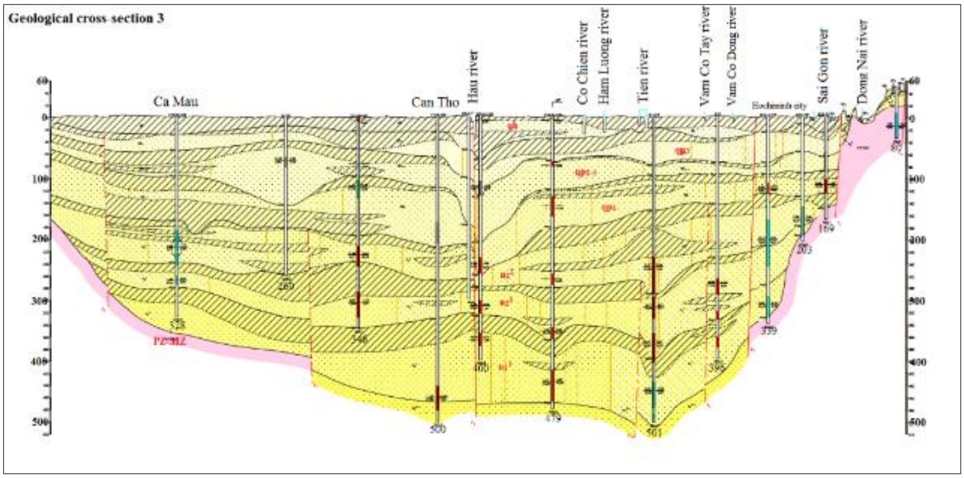

Fig. 1. Hydrogeological cross-section of the Nambo Plain

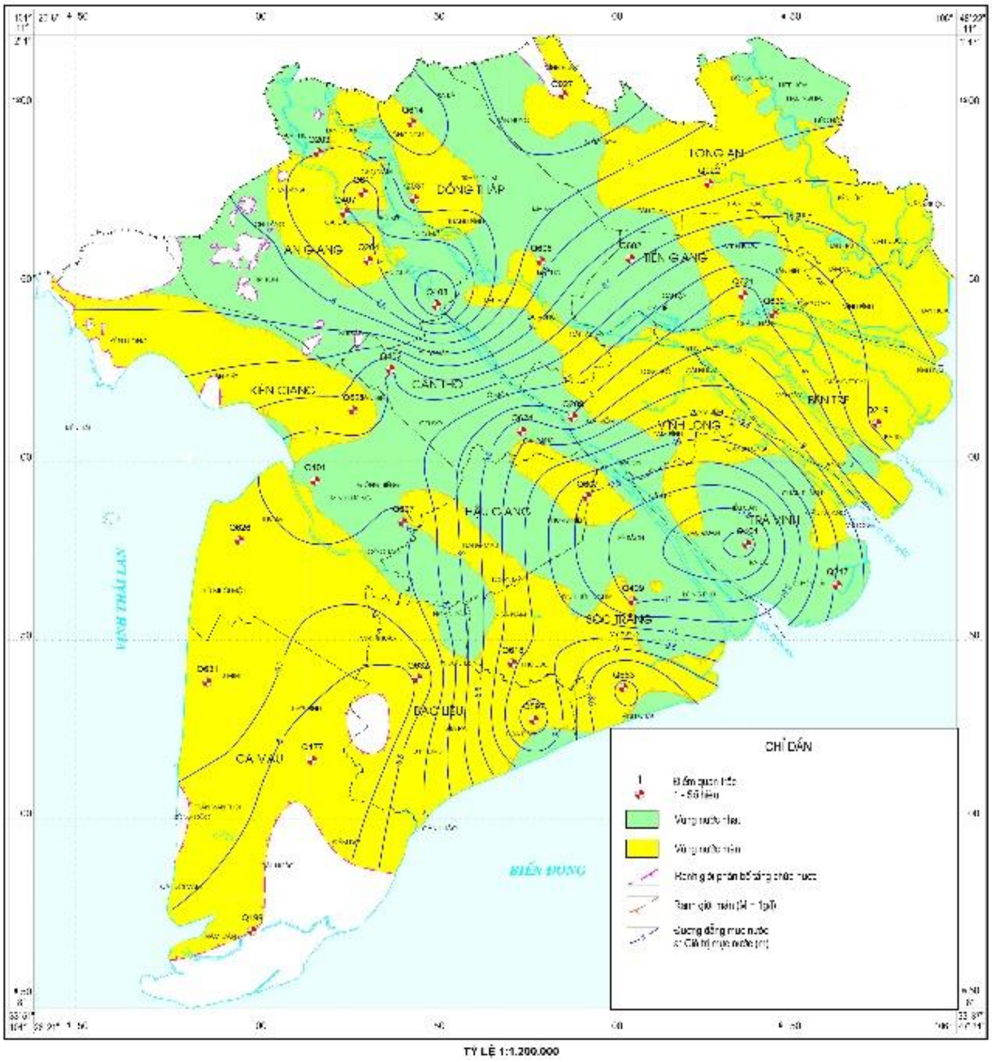

Fig. 2. The fresh-saline distribution map of the Upper Pleistocene aquifer in Nambo Plain

In the existing aquifers, the upper Pleistocene is directly influenced by rainfall and has a relationship with meteoric water [10]. This aquifer is formed by upper Pleistocene sediments of river origin and marine origin. Outcropping in some parts of the Nambo Plain, the remains of the upper Pleistocene are directly overlaid by the Holocene aquifer.

The fresh groundwater in the Nambo Plain is distributed in the form of lens and is originated from meteoric water [12]. The upper Pleistocene aquifer is outcropping in Dong Nambo and some parts in Tri Ton, Ha Tien, where occurs the infiltration of precipitation and surface water into upper Pleistocene aquifer as a recharge source. The fresh-saline distribution map of the Upper Pleistocene aquifer in Nambo Plain is illustrated in Figure 2.

Statistical data from 690 boreholes show that the depth to the aquifer roof ranges from 0.0 m to 115.4 m, an average of 47.9 m; depth to bottom from 11.5 m to 154.0 m, average 76.4 m; the thickness of aquifer is from 2.0 m to 84.0 m, average 29.1 m. The water storage capacity ranges from poor to rich, water quality is poor in many places, saline in a large area, and can hardly be exploited to supply for daily activities. The total exploitation capacity of the upper Pleistocene is about 114,945 m^3/day. The recharged source for this aquifer is mainly from the surrounding (in the Dong Nambo and in the Cambodian land) and partly infiltrates from the adjacent aquifer [10, 11].

III. METHODOLOGY

The subject of this study is the upper Pleistocene aquifer in Nambo Plain.

To study the recharge ability of the upper Pleistocene aquifer from rainwater, a sampling network based on the actual monitoring wells is being set up. GW samples were collected for stable isotopes, tritium and ^{14}C analysis. The relationship between δ^2H and δ^{18}O values of GW is used to identify the origin of GW. Tritium and ^{14}C contents are used to determine GW age. Based on the origin and age of GW to estimate the modern recharge ability of study GW aquifers [5-7, 13].

To evaluate the recharge ability of the study aquifer by river water, GW adjacent to the river and river water were sampled for investigating the relationship between the isotopic composition both of river water and GW. Water samples are analyzed for ^{2}H, ^{18}O, ^{3}H and ^{14}C to evaluate the interaction between the river water and GW.

A total of 48 GW samples of the upper Pleistocene aquifer, 16 river water samples and 14 GW samples adjacent to the river were collected according to the Sampling Procedures for Isotope Hydrology of IAEA [14]. Sites for sampling GW are shown in Figure 3. The blue circle points are the river water sampling locations and the purple, orange and red square points are fresh, brackish and saline GW sampling locations.

The stable isotopes ^{18}O and ^{2}H were analysed using a DLT-100 Liquid-Water Isotope Analyzer (Los Gatos Research, Inc.) These isotopic compositions are expressed as parts per thousand (‰) in δ–notation as deviations of heavy to light isotopic ratios relative to an international standard SMOW (Standard Mean Ocean Water) or the equivalent VSMOW, as defned by:

$$\delta\ (‰) = \frac{R_s - R_{std}}{R_{std}} x\ 1000$$

Where, R_s and R_{std} denote the ratio of heavy to light isotope (^{2}H/^{1}H or ^{18}O/^{16}O) in the sample and the standard respectively [15]. The analytical precision is about 1.0‰ for δ^2H and 0.15‰ for δ^{18}O.

The radioactive isotopes ^{3}H and ^{14}C were analysed using a TRICARB 3170/TR/SL low-level liquid scintillation counting spectrometer (Parkard, USA). Before counting, tritium in waters should be enriched by electrolysis and ^{14}C in waters should be converted into benzene by synthesis. Tritium concentration is measured in TU (Tritium Unit, 1TU=0.119 Bq/L) [16]; ^{14}C content in the samples is expressed in PMC (Percent of Modern Carbon) which is the ratio of the ^{14}C activity in the analyzed sample to that of a modern carbon standard, expressed in per cent. (Ox. II, NIST, USA with a ^{14}C activity of 0.2147 Bq/gC) [15].

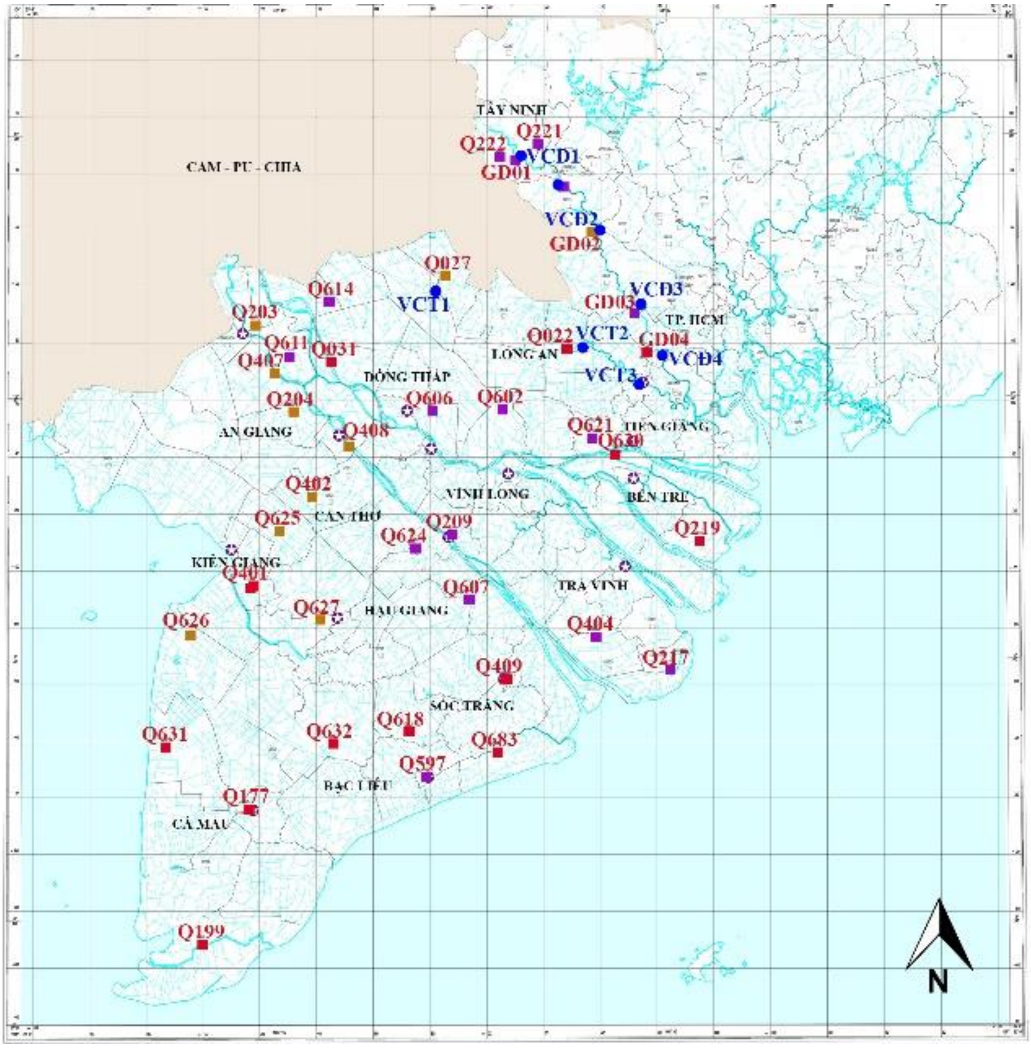

Fig. 3. Sites for sampling groundwater & river water

IV. RESULTS AND DISCUSSION

Recharge ability by modern rainwater

Analytical data of 48 samples of the upper Pleistocene aquifer shows that stable isotope compositions of fresh GW vary in a rather narrow range, from -7.71‰ to -4.99‰ for δ^{18}O and from -53.4‰ to -37.9‰ for δ^2H while those of brackish GW vary in a wider range, from -8.17‰ to -5.75‰ for δ^{18}O and from -57.4‰ to -39.9‰ for δ^2H. Most variables in a fairly large range are the stable isotope compositions of saline GW, from -7.03‰ to -1.63‰ for $\delta^{18}O$ and from -55.3‰ to -10.3‰ for δ^2H. The variation of stable isotope compositions shows that the fresh GW is not mixing like brackish and saline GW.

The fact of mean stable isotope values of saline GW ($\delta^{18}O_{mean}$ = -4.72‰ and δ^2H_{mean} = -30.2‰) are higher than those of fresh GW ($\delta^{18}O_{mean}$ = -6,58‰ and δ^2H_{mean} = -45,6‰) means that saline GW is richer in heavy isotopes. Independent t-test comparing the mean values of $\delta^{18}O$ and δ^2H of two groups of saline and fresh GW shows a significant difference (t=3.580; df = 19.70; $p<0.05$ for $\delta^{18}O$ and t=3.657; df=16.64; $p<0.05$ for δ^2H). These suggest that saline GW is the result of mixing of fresh GW with water enriched in the heavy isotopes.

The relationship between δ^2H and $\delta^{18}O$ of GW samples, global meteoric water line (GMWL) and local meteoric water line (LMWL) are described in Figure 4.

The distribution along and close the GMWL of fresh GW (blue points) shows the meteoric origin [5]. The brackish and saline GW (orange and red points) are distributed along the GMWL in a separated line showing that brackish and saline GW is result of the mixing of fresh GW with a high mineral salt and richly heavy isotopes water.

Figure 5 shows that the relationship between Cl^- concentration and $\delta^{18}O$ value in brackish and saline GW is linear (R^2 = 0.84) and tends to cross the point representing for seawater, indicating that fresh GW mixed with saline GW of marine origin.

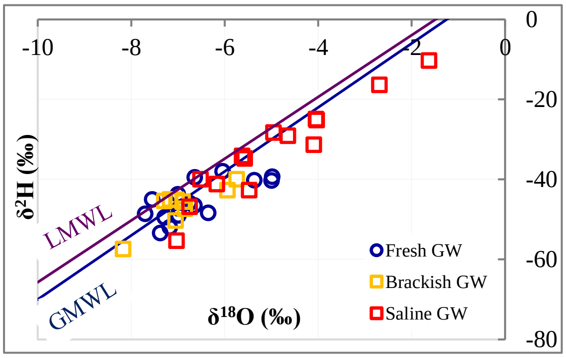

Fig. 4. Relation between δ^2H and $\delta^{18}O$ of GW

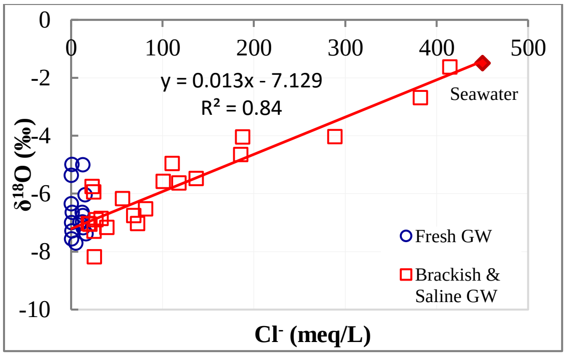

Fig. 5. Relation between $\delta^{18}O$ and Cl^- concentration in brackish and saline groundwater

In some GW samples such as Q222, GD01 (Chau Thanh) Q221 (Tay Ninh City), Q023 (Trang Bang), GD05 (Ben Cau), tritium values and ^{14}C contents are quite high as established in Table I.

Table I. Tritium values and ^{14}C contents of some upper Pleistocene groundwater samples

No	Samp. code	Cond. (μS/cm)	δ^2H (‰)	$\delta^{18}O$ (‰)	^3H (TU)	^{14}C (pmC)
1	Q222	85	-45.1	-7.12	0.91±0.17	103.8±1.8
2	GD01	42	-41.2	-7.35	0.91±0.17	99.7± 2.2
3	Q221	392	-38.6	-7.06	0.82±0.13	101.4±2.1
4	GD05	49	-48.3	-6.35	0.79±0.15	106.9±2.6
5	Q023	632	-40.3	-5.89	1.03±0.24	104.5±3.0

The tritium values are the same as those in rainwater in the Nambo Plain (about 1.2 TU), and the ^{14}C contents are similar to those in modern ^{14}C standard samples, showing that upper Pleistocene GW is young water due to infiltration of modern rainwater or surface water. According to the hydrogeological characteristics and cross sections in study area, the upper Pleistocene aquifer roof is deeply submerged in the area between the Tien and Hau Rivers, raised to the north of the Tien River and south of the Hau River; especially, the aquifer roof is very high in the northern area (along the Vietnam - Cambodia border); thus, the aquifer may be outcropping in the Dong Nambo (Tay Ninh province). On the other hand, these sampling locations are far from the Vam Co River; therefore, it can be concluded that the upper Pleistocene GW is young water due to the infiltration of modern rainwater or that this aquifer is recharged by rainwater and Tay Ninh province is a recharge zone of this aquifer.

Hydraulic relationship between Vam Co Dong River and groundwater

The isotope compositions in Tien, Hau, Vam Co Dong (VCD), and Vam Co Tay (VCT) River are described in Figure 6. From upstream to downstream, river water samples were collected both in dry and rainy seasons at 2 sampling points in Hau River, 3 sampling points in Tien River, 2 sampling points in VCT River and 4 sampling points in VCD River.

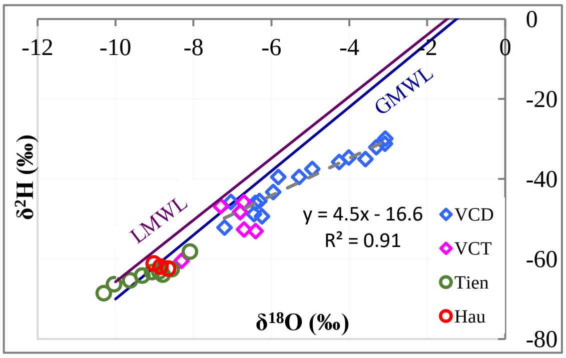

Fig. 6. Relation between δ^2H and $\delta^{18}O$ of Mekong and Vam Co River water

The results show that water samples from Tien River and Hau River are depleted in heavy isotopes relative to those from VCD and VCT River. It is because the large Mekong River originates in the Tibetan Plateau which is on a high latitude area and far from moisture. Rainwater and snow in this area are depleted in heavy isotopes due to latitude and altitude effects. From upstream to downstream, the isotopic compositions of the Tien River water are more variable than those of the Hau River.

Vam Co Dong and Vam Co Tay are smaller rivers, the flow path is short, the evaporation is occurred in the VCD and VCT River but evaporation in the VCD River is stronger. One of the reasons may be that, although originating from the same area in Cambodia, the VCT River is also supplied with water from the Mekong River through the branches of Preak Banam and Preak Trabeak in Cambodia. From upstream to downstream and over time, the relationship between the $\delta^{18}O$ and δ^2H values of VCD River water with R^2 = 0.91 and slope is 4.5 (<6) indicating for evaporation [5]. This base can be used to study the hydraulic relationship between river water and GW.

Figure 7 shows the relationship between the $\delta^{18}O$ and δ^2H values of the Mekong, Vam Co River water and upper Pleistocene GW. The significant difference in stable isotopic compositions of Mekong River water and upper Pleistocene GW confirms that there is no hydraulic relationship between them while the points representing for Vam Co River and upper Pleistocene GW are distributed in the same part. It means that there should be a hydraulic relationship between the Vam Co River water and upper Pleistocene GW.

Due to GW adjacent to the VCT River being saline, there are not many mining wells for studying. In this study, we only evaluate the hydraulic relationship between VCD River and upper Pleistocene GW.

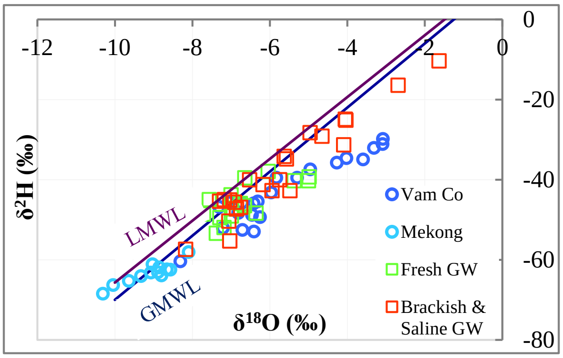

Fig. 7. Relation between δ^2H and δ^{18}O of upper Pleistocene groundwater and river water

To study the hydraulic relationship between the VCD River and upper Pleistocene GW using isotope techniques, 04 monitoring points are arranged along the VCD River with 04 sampling points for upper Pleistocene GW adjacent to the VCD River. Both of River water and GW are collected periodically to monitor stable isotope compositions. The results are listed in Table II.

The relationship between the δ^{18}O and δ^2H values of VCD River water samples and upper Pleistocene GW adjacent to the VCD River is described in Figures 8, 9, 10 and 11. From upstream to downstream, the samples were collected at 04 sampling locations: Ben Soi (Chau Thanh, Tay Ninh); La Mai (Trang Bang, Tay Ninh); Duc Hoa; Ben Luc (Long An).

Table II. The isotope composition in VCD River and upper Pleistocene GW adjacent to the VCD River

Group/ Sampling time	δ^2H (‰)	δ^{18}O (‰)	^{3}H (TU)	δ^2H (‰)	δ^{18}O (‰)	^{3}H (TU)
Group 1:	**VCD1**			**GD01**		
1st time: 08/2020	-50.1	-7.21	1.43±0.20	-43.1	-7.14	0.91±0.17
2nd time: 11/2020	-45.5	-6.31	1.50±0.24	-45.0	-7.56	1.02±0.22
3rd time: 01/2021	-39.5	-5.83	0.85±0.12	-47.4	-7.49	1.27±0.28
4th time: 04/2021	-34.6	-4.01	0.86±0.23	-45.9	-6.12	1.17±0.18
Group 2	**VCD2**			**GD02**		
1st time: 08/2020	-45.7	-7.04	1.00±0.15	-45.6	-6.90	-0.05±0.14
2nd time: 11/2020	-43.2	-5.96	1.39±0.24	-48.2	-6.91	-0.28±0.18
3rd time: 01/2021	-39.5	-5.29	0.99±0.21	-48.3	-7.22	0.14±0.11
4th time: 04/2021	-32.1	-3.31	1.61±0.17	-	-	-
Group 3	**VCD3**			**GD03**		
1st time: 08/2020	-48.3	-6.81	1.16±0.13	-	-	-
2nd time: 11/2020	-45.9	-6.42	1.50±0.28	-37.9	-6.04	0.38±0.21
3rd time: 01/2021	-35.8	-4.26	1.02±0.17	-36.6	-5.19	0.67±0.21
4th time: 04/2021	-31.1	-3.08	1.26±0.10	-34,4	-3.52	0.60±0.09
Group 4	**VCD4**			**GD04**		
1st time: 08/2020	-48.8	-6.45	1.23±0.19	-	-	-
2nd time: 11/2020	-46.4	-6.25	1.02±0.27	-42.8	-5.75	0.19±0.17
3rd time: 01/2021	-37.5	-4.95	1.26±0.18	-33.1	-5.12	0.40±0.20
4th time: 04/2021	-29.9	-3.08	1.31±0.20	-31.5	-3.22	0.35±0.28

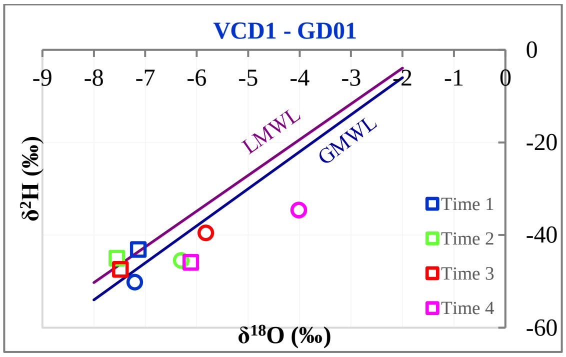

Fig. 8. Relation between δ^2H and δ^{18}O of VCD1 river and GD01 groundwater

Figure 8 shows that the stable isotope compositions of GW in three first times were similar, while those of river water became more enriched over time. In the last time (04/2021), the isotope compositions of GW became enriched similarly to these of river water. This means VCD river water interacted with upper Pleistocene GW at the end of dry season and river water infiltrated into GW. Although the tritium values of GW are similar to those in river water, it is mainly infiltration of modern rainwater because the aquifer is recharged from river water only at the end of the dry season.

Figure 9 shows that the stable isotope compositions of GW were similar in all sampling times, while those of rivers became more enriched due to evaporation. There was no tritium in GW of GD02. These show that there was not interaction between VCD river water and upper Pleistocene GW at this location.

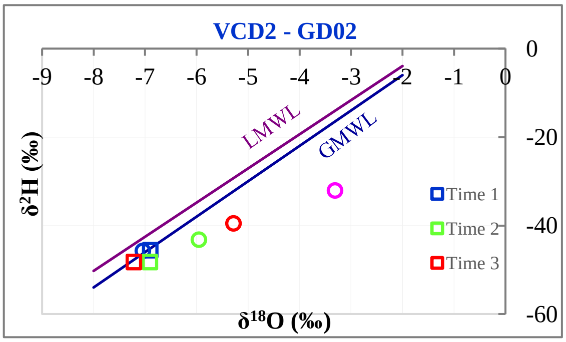

Fig. 9. Relation between δ^2H and δ^{18}O of VCD2 river and GD02 groundwater

Both Figures 10 and 11 show that the stable isotope compositions of VCD river water and GW adjacent to the VCD River were covariate and became more enriched over time. That means there was a hydraulic interconnection between river water and GW, river water was recharged into GW. The tritium values of GW also indicate the presence of river water in GW at 2 these sampling points.

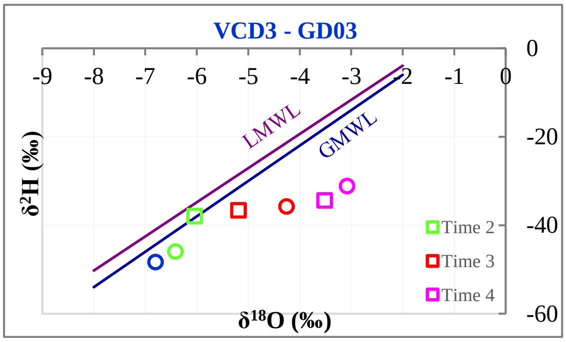

Fig. 10. Relation between δ^2H and δ^{18}O of VCD3 river and GD03 groundwater

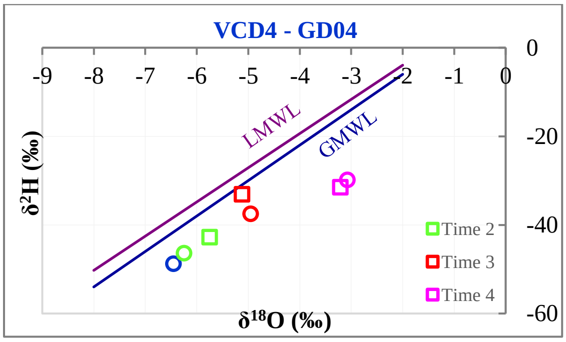

Fig. 11. Relation between δ^2H and δ^{18}O of VCD4 river and GD04 groundwater

The obtained results show that there was a hydraulic relationship between the upper Pleistocene aquifer and the VCD River. At Ben Soi (Chau Thanh, Tay Ninh), the river water is recharged into GW at the end of the dry season, in the remaining time GW drains into the river; at La Mai (Trang Bang, Tay Ninh), the river water is not recharged into GW; the VCD River in Long An province, from Duc Hoa to Ben Luc, the river water infiltrates into the aquifer during the study period.

V. CONCLUSIONS

Although the study is still ongoing, the data available to date shows that:

Groundwater in the upper Pleistocene aquifer at the Nambo Plain is originated from meteoric water and formed at different stages. The saline GW is the result of the mixing of fresh GW with saline GW of marine origin. The upper Pleistocene aquifer has modern rainwater infiltrated as a recharge source. The recharge zone of the upper Pleistocene aquifer possible is a part of Tay Ninh province (bordering Vietnam - Cambodia). To clarify this identification, the upper Pleistocene water samples in Dong Nambo should be collected and analysed for isotope compositions.

There is a hydraulic relationship between the upper Pleistocene aquifer and the Vam Co Dong River. From Duc Hoa to Ben Luc, Long An province, the river water infiltrates into the aquifer. In La Mai and Ben Soi (Tay Ninh): mainly GW discharges into the river. The assessment of the recharge rate should be carried out in the future.

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