App. Envi. Res. 38 (3): 49-58

Applied Environmental Research

Journal homepage : http://www.tci-thaijo.org/index.php/aer

Isotope Evidence of Rainfall and Groundwater for Tracing Recharge Areas in Kaeng Khoi District, Saraburi Province, Thailand

Wanlapa Wisittammasri[1], Srilert Chotpantarat[1,2,3,*]

[1] Department of Geology, Faculty of Science, Chulalongkorn University, Bangkok 10330 Thailand

[2] Research Program of Toxic Substance Management in the Mining Industry, Center of Excellence on Hazardous Substance Management (HSM), Chulalongkorn University, Bangkok 10330 Thailand

[3] Research Unit of Site Remediation on Metals Management from Industry and Mining (Site Rem), Chulalongkorn University, Bangkok 10330 Thailand

[*] Corresponding author: Email: csrilert@gmail.com

Article History
Submitted: 26 August 2016/ Accepted: 3 October 2016/ Published online: 30 November 2016

Abstract

This study was conducted in the districts of Kaeng Khoi and Muang, located in the center of Saraburi province, Central Thailand. The purpose was to use a stable isotope technique to identify recharge areas where rainfall infiltrates. Analysis of stable isotopes in groundwater, surface water and rainwater were conducted in September 2014. Isotope compositions of groundwater were found to have δD values that ranged from -37.55‰ to -48.04‰ while δ18O values ranged from -5.30‰ to -7.34‰. The Local Meteoric Water Line (LMWL) in the study area was indistinguishable from the Bangkok Local Meteoric Water Line (BKK LMWL), and the stable isotope values of rainwater in area were more depleted than BKK LMWL. The isotope compositions of surface water revealed that the effect of evaporation could divide the groundwater into two groups, with the first group locally receiving rainfall and the second group interacting directly with surface water. Therefore, care must be taken to prevent groundwater contamination in the latter group due to polluted surface water caused by human activities.

Keywords: Groundwater; Kaeng Khoi district; Recharge; Stable isotope

Introduction

Contamination of surface water can occur at both point and non-point sources such as agricultural and industrial areas much more easily than in groundwater resources. The generally higher quality of groundwater partly explains why groundwater is generally favoured in both agriculture and industry. However, rapid increases in water demand over the last few decades has resulted in severe water shortages.

Receding water tables have resulted in land subsidence and erosion as well as seawater intrusion, often due to excessive pumping [1-2]. In addition, groundwater quality has degraded due to increasing contamination by toxic substances released entering into surface water and eventually infiltrating groundwater aquifers.

A recharge area is an area where rainfall can infiltrate and directly reach the subsurface aquifer. These areas are so important that they need to be identified to better understand groundwater flow systems and to develop long-term water management plans. Oxygen and hydrogen isotopes of water can serve as a tool to study the movement of groundwater and interaction between surface water and groundwater. The isotopic ratio of oxygen (δ^{18}O) and hydrogen (δD) in water can be used to trace the source of groundwater, since the ratios of δ^{18}O and δD in seawater, glaciers, water vapor, precipitation and run-off are all different, depending on vapor pressure, humidity, altitude, temperature and evaporation [3-8]. This information can help characterize a groundwater system and estimate the long-term usage of groundwater consumption so it will not exceed groundwater inflows; this information can be used to protect the recharge areas from potential sources of contamination [9].

The purpose of this study was to investigate stable isotope ratios and use this isotope information to identify the recharge area surrounding Chulalongkorn University grounds and facilities located in Kaeng Khoi district, Saraburi (Figure 1). The population living in this area has long experienced water shortages. Such stable isotope information can also be used to define recharge areas, groundwater sources and interaction between surface water and groundwater. The understanding of the groundwater system gained through this study can be used as a basis for improving the water management plan.

Materials and Methods

1) Study area

The study area was a watershed located in the southern sector of Kaeng Khoi district and the eastern part of Muang district, Saraburi Province, central Thailand (Figure 1). The size of the study area is approximately 314 km^2. According to the topographic map, the area consists of a high plain in the east and an alluvial plain and floodplain to the west. The geology of the area consists of Permian-Triassic extrusive volcanic rock and quarternary alluvial deposits. A volcanic aquifer, ranging in depth from ~20-40 m deep (in the east) to > 60 m deep (in the west), is the main groundwater resource in the study area. The area supports crops including rice, cassava, corn and sugarcane. Average annual temperature is approximately 28.8^{O}C [10], with an average annual rainfall of approximately 1,192.6 mm [11].

2) Stable isotope ratio measurements

Forty-four groundwater, 14 surface water and 10 rainwater samples were collected during 10-13 September 2014. The depth of groundwater samples ranged from 14-210 m. Each sample was filtered through a disposable syringe filter Nylon membrane with 0.45 μm pore size to avoid clogging of injection prior to analyzing the stable isotopes (oxygen and deuterium) at the Thailand Institute of Nuclear Technology (TINT). The oxygen and deuterium isotope ratios were analyzed by Cavity Ring-Down Spectroscopy (CRDS) technique (Model Picarro L21-30*i*) [12]. The isotope ratio were expressed in delta (δD and δ^{18}O) values and compared with the Vienna Standard Mean Ocean Water (VS MOW), which are typically reported in "permil" (‰, parts per thousand). The inhouse standard IAEA consist of STD1 was -11.90‰ for δ^{18}O and -93.95‰ for δD, STD2 was 1.61‰ for δ^{18}O and 3.77‰ for δD and STD3 was -5.72‰ for δ^{18}O and -40.02‰ for δD. The average precision was 0.08‰ for $\delta^{18}O$ and 0.35‰ for δD. Accuracy was 98.99% and 94.57% for $\delta^{18}O$ and δD, respectively [13].

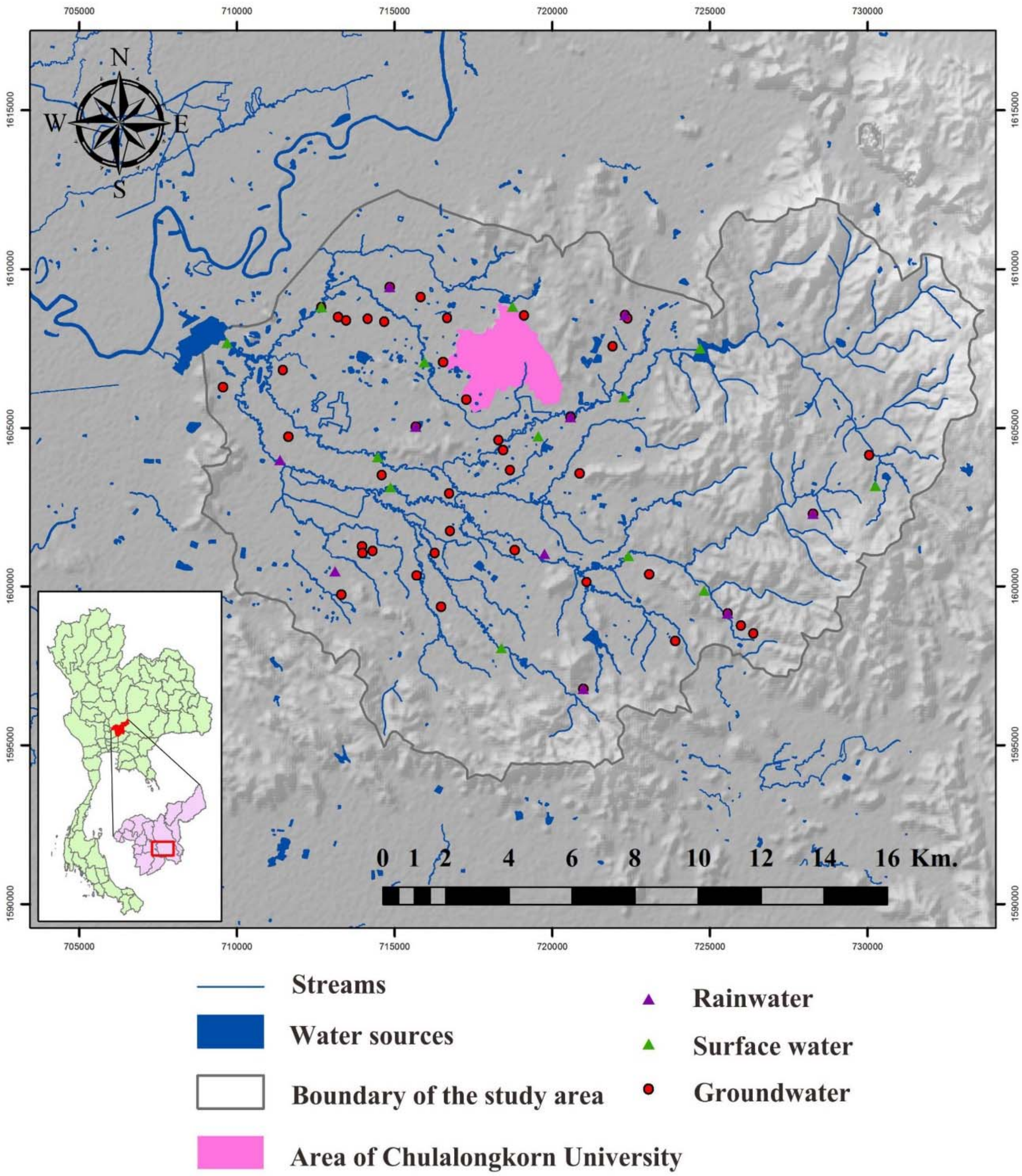

Figure 1 Sampling locations of groundwater, surface water and rainfall in the study area

Results and Discussion

The analysis results of water samples were compared with the mean stable isotope compositions (δD, $\delta^{18}O$) in rainfall of the Bangkok station, known as "Bangkok Local Meteoric Water Line (BKK LMWL)", which was created from a long-term dataset and collected by The Global Network for Isotopes in Precipitation (GNIP, 4845500) (data from the International Atomic Energy Agency [14]) and are shown in Figure 2a.

As a result, the linear relationship between δD and $\delta^{18}O$ could be analyzed using the following equation: $\delta D = 7.329\ \delta^{18}O + 5.1652$, for comparison of isotope characteristics of water samples in this study. According to the stable isotope data of rainfall in the study area, it was found that the local meteoric water line (LMWL) relatively resembled the BKK LMWL and could be expressed by the following equation: $\delta D = 7.1755\,\delta^{18}O + 3.4789$ as shown in Figure 2b. Since the study area is located in central Thailand, approx. 107 km away from Bangkok, climatic conditions are relatively similar. However, the slope of LMWL was slightly lower, showing that rainfall came from a vapor source with a slightly high humidity [15-16]. Moreover, the isotope characteristics mainly showed an increase in delta values, reflecting warmer weather and lower altitude as a result of the initial period of rainfall or pre-monsoon period [17]. The $\delta^{18}O$ and δD ranged from -7.83‰ to -4.59‰ and -54.18‰ to -30.00‰ with average values of -6.50+1.12‰ and -43.17+8.19‰, respectively (Table 1).

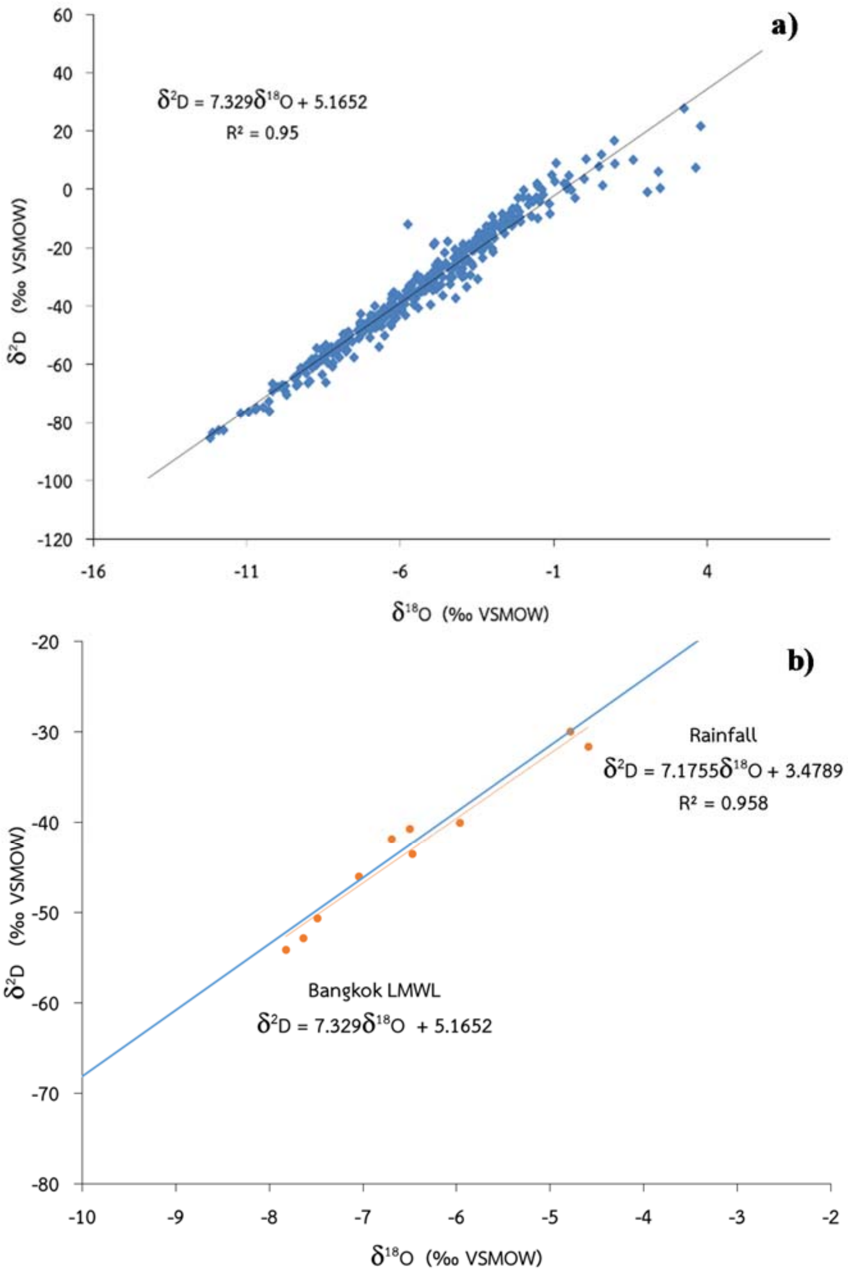

Figure 2 Plots of δD and $\delta^{18}O$ of rainfall (a) BKK LMWL during 1968-2009 [14] and (b) LMWL in 2014 compared with BKK LMWL

The $\delta^{18}O$ and δD of the surface water samples ranged from -7.49‰ to -4.71‰ and -49.13‰ to -37.50‰ with average values of -6.34+0.77‰ and -43.07+3.67‰, respectively (Table 1). Comparing the stable isotope data of surface water with the BKK LMWL, it was found that the relationship between δD and $\delta^{18}O$ of surface water in the area differed from that of BKK LMWL. The regression line of surface water deviated from the BKK LMWL and intercepted with the BKK LMWL at δD of -46‰. Since surface water is directly exposed to the atmosphere, when rain falls onto surface water with low relative humidity and high temperature, it will evaporate quickly, resulting in a different fractionation of isotope composition from the BKK LMWL. A linear regression analysis of surface water as shown in the following equation: $\delta D = 4.2485\ \delta^{18}O - 15.935$ had a slope of evaporation line ranging between 4 and 5, expressing moderate relative humidity (25%-75%) [18]. Furthermore, the samples from ST43, ST51 and ST53 were plotted on the slope of BKK LMWL, indicating that these samples were in a high altitude area where the water did not evaporate.

Table 1 The stable isotope data of groundwater, surface water and precipitation

Station	Easting	Northing	$\delta^{18}O$ (‰)	δD (‰)
		Groundwater		
ST01	716539	1607076	-6.62	-43.54
ST02	717275	1605897	-6.75	-45.88
ST03	718440	1604309	-6.51	-43.40
ST04	719867	1602920	-6.88	-45.70
ST05	718300	1604615	-6.69	-43.95
ST06	730059	1604144	-6.77	-45.17
ST07	728277	1602291	-7.15	-47.02
ST11	722311	1608558	-6.97	-46.67
ST12	722399	1608447	-6.83	-45.25
ST13	720870	1603571	-7.24	-47.89
ST15	720578	1605334	-6.48	-43.18
ST17	719117	1608537	-6.32	-43.42
ST19	714853	1609432	-6.02	-41.02
ST21	715830	1609126	-6.05	-41.65
ST22	716671	1608466	-6.00	-42.53
ST23	712684	1608809	-5.30	-37.55
ST25	713202	1608493	-7.05	-47.32
ST26	713464	1608383	-6.40	-43.28
ST27	714156	1608442	-5.91	-40.99
ST28	714671	1608348	-6.08	-42.17
ST29	711461	1606825	-7.01	-47.25
ST30	711461	1606825	-6.62	-44.09
ST32	709563	1606287	-5.99	-41.61
ST35	711636	1604727	-6.41	-42.79
ST37	713973	1601267	-7.08	-47.99
ST38	714315	1601126	-6.84	-45.54
ST39	713975	1601057	-6.90	-47.08
ST40	713311	1599740	-6.90	-45.44
ST42	715703	1600345	-6.85	-45.07
ST44	720988	1596769	-5.83	-39.86
ST46	723906	1598275	-6.90	-45.67
ST47	726386	1598514	-7.03	-45.44
ST48	725990	1598761	-7.34	-48.04

Table 1 The stable isotope data of groundwater, surface water and precipitation (*continued*)

Station	Easting	Northing	δ18O (‰)	δD (‰)
ST50	725570	1599148	-7.11	-46.19
ST52	723083	1600389	-7.09	-46.29
ST48	725990	1598761	-7.34	-48.04
ST56	715669	1605038	-6.92	-46.22
ST58	714592	1603520	-6.68	-44.34
ST59	716739	1602934	-6.25	-43.17
ST60	716759	1601752	-6.74	-45.16
ST61	716278	1601055	-6.75	-45.34
ST62	716478	1599358	-6.64	-43.87
ST63	718808	1601157	-6.24	-42.25
ST65	721091	1600142	-6.04	-40.52
ST67	721925	1607575	-6.69	-43.77
ST63	718808	1601157	-6.24	-42.25
ST65	721091	1600142	-6.04	-40.52
ST67	721925	1607575	-6.69	-43.77
Average			-6.63	-44.41
Min.			-7.34	-48.04
Max.			-5.30	-37.55
Standard			0.45	2.40
		Surface water		
ST09	730253	1603172	-6.71	-44.69
ST14	718745	1608815	-6.78	-45.79
ST18	722288	1605971	-4.71	-37.50
ST24	712684	1608809	-5.35	-37.82
ST31	709687	1607677	-6.00	-40.20
ST34	711368	1603989	-6.35	-42.18
ST36	714868	1603135	-6.65	-44.35
ST43	718397	1598054	-6.89	-44.88
ST51	724824	1599866	-7.49	-49.13
ST53	722422	1600966	-7.39	-48.54
ST54	715946	1607073	-5.84	-40.05
ST57	714471	1604079	-5.87	-39.89
ST66	724687	1607510	-6.78	-45.52
ST68	719564	1604736	-5.99	-42.37
Average			-6.34	-43.07
Min.			-7.49	-49.13
Max.			-4.71	-37.50
Standard			0.77	3.67
		Precipitation		
ST08	728277	1602291	-7.04	-46.07
ST10	722311	1608558	-4.79	-30.00
ST16	720578	1605334	-4.59	-31.65
ST20	714853	1609432	-6.50	-40.75
ST33	711368	1603989	-5.97	-40.09
ST41	713110	1600480	-7.49	-50.70
ST45	720988	1596769	-7.83	-54.18
ST49	725570	1599148	-6.69	-41.87
ST55	715669	1605038	-6.47	-43.56
ST64	719755	1601038	-7.64	-52.85
Average			-6.50	-43.17
Min.			-7.83	-54.18
Max.			-4.59	-30.00
Standard			1.12	8.19

The intercept point (Figure 3) could specify the approximate position of average annual rainfall, which could preliminarily be separated between high and low altitude [19]. The $\delta^{18}O$ and δD of the groundwater samples ranged from -7.34‰ to -5.30‰ and -48.04‰ to -37.55‰ with average values of -6.63+0.45‰ and -44.41+2.37‰, respectively (Table 1). According to the isotopic compositions of groundwater, the hydrogen and oxygen isotope compositions in some groundwater samples corresponded well to those of the BKK LMWL (Group 1), accounting for 63.63% of all groundwater samples. This could be possible because the stations are located in recharge areas that receive rainfall directly. However, most groundwater samples were agglomerated, while only 4 stations, ST01, ST05, ST62 and ST67, presented low delta values, indicating that these stations were probably located at low altitude or where there was mixing with rainfall in the summer season, when weather is warmer (Figure 4) [20]. The remaining 11 groundwater samples (Group 2) were distributed along the evaporation line. These samples could have been recharged from surface water or interacted with surface water [18]. In other words, these areas did not receive recharge water directly from rainfall (Figure 3).

The groundwater wells (Group 1) received rainfall directly that was distributed over the study area. It was found that the eastern area, a high plain where most groundwater wells are located, could be recharge areas for a confined aquifer while the central area, a floodplain, is where most groundwater wells are located in a shallow aquifer. The groundwater wells (Group 2), which interact with surface water, are mainly distributed in the central and western plains. Thus, it should be a vital concern that the area is used appropriately because contaminated surface water can so easily infiltrate and contaminate groundwater resources. The recharge area is delineated by isotope data of Group 1 along with fault zones. The fault and fracture zones increase secondary porosity and permeability in hard rock, resulting in rapid infiltration of rainfall into groundwater aquifers (Figure 4).

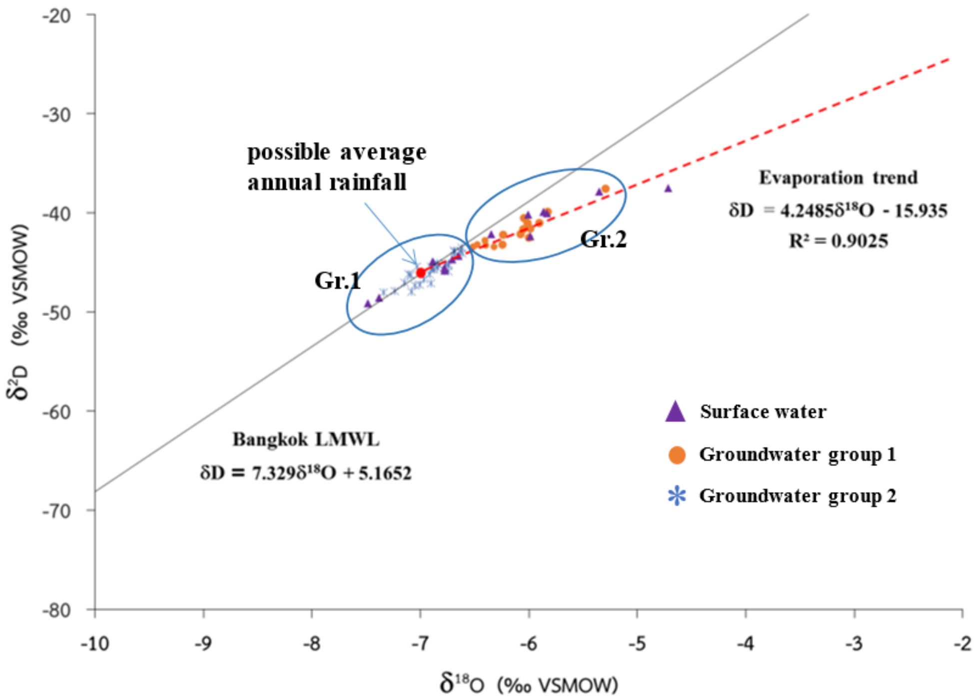

Figure 3 Plot of δD and $\delta^{18}O$ of surface water and groundwater compared with BKK LMWL

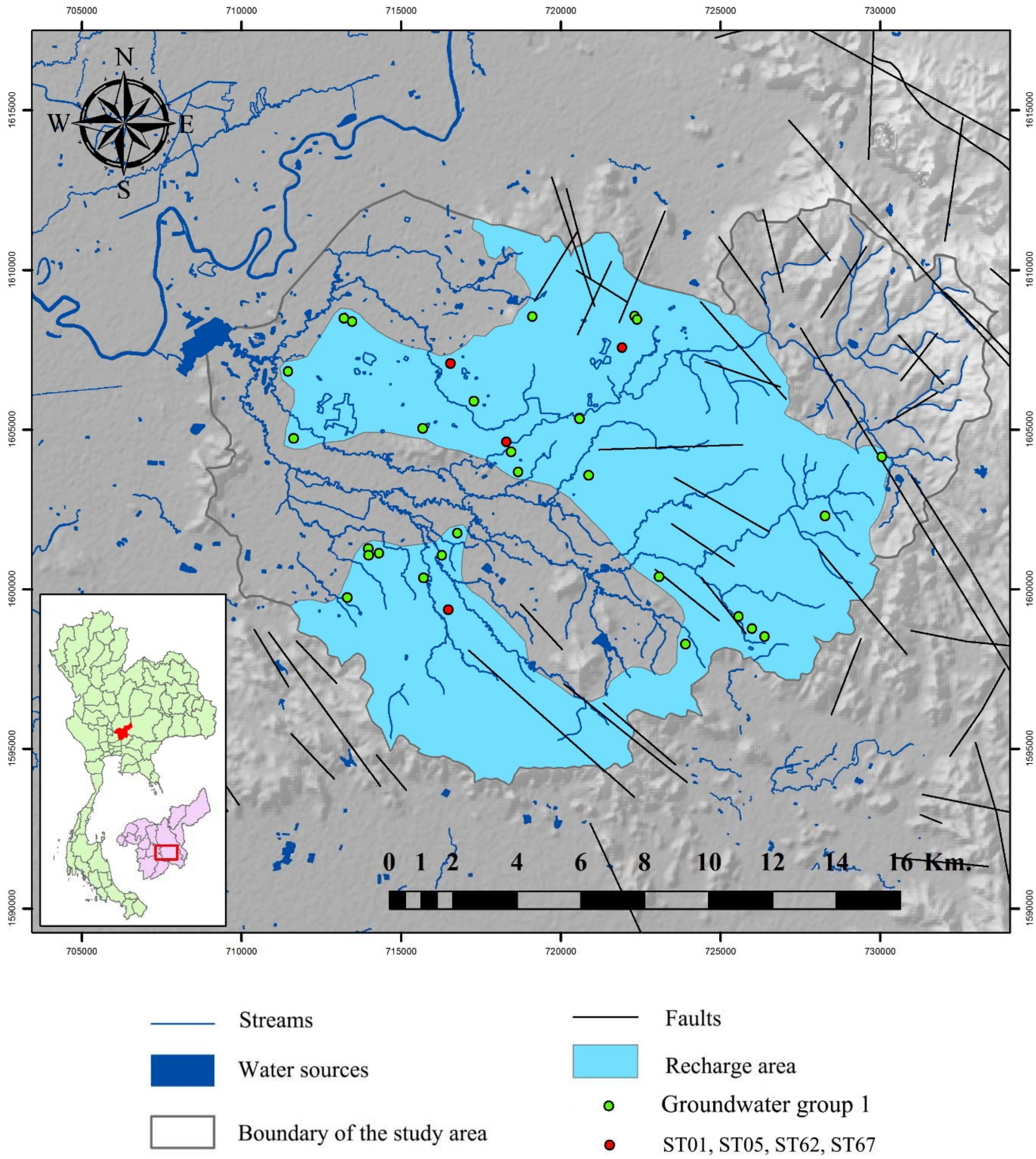

Figure 4 Recharge area

Conclusions

Analysis of the dual stable isotope data of water offer a practical tool for preliminary evaluation of recharge and discharge areas. The dual isotope compositions were classified into two groundwater groups: 1) local wells that receive rainfall; and 2) wells that intermix with surface water. As groundwater is unaffected by evaporation, the evidence of evaporation found in groundwater indicates interaction with surface water, which has a high evaporation rate and different isotopic signature. To produce a more complete interpretation of the groundwater systems, other information is required, for example as may be obtained using other isotopes such as tritium (^{3}H) and carbon (^{14}C), to study the age of groundwater [21]. In addition, physical and hydrochemical data in groundwater can be used to study groundwater movement, including groundwater contamination. These are all useful for the study of a hydrogeology system. Finally, studies of this type can lead to the protection and management plan for groundwater resources.

Acknowledgements

This research would not have been successful without the help of the Thailand Institute of Nuclear Technology (TINT), Department of Geology, Faculty of Science, Chulalongkorn University. The authors would also like to express our appreciation to Mr. Nitipon Noipow, who shared his extensive knowledge about stable isotopes. We would also like to express our sincere thanks to the 90th Anniversary of the Chulalongkorn University Fund, Ratchadaphiseksomphot Endowment Fund, the National Research Council of Thailand (NRCT), the Grant for International Research Integration: Chula Research Scholar, Ratchadaphiseksomphot Endowment Fund (GCURS-59-06-79-01), the Office of Higher Education Commission (OHEC) and the S&T Postgraduate Education and Research Development Office (PERDO) for the financial support of the Research Program and thanks to the Ratchadaphiseksomphot Endowment Fund, Chulalongkorn University for the Research Unit.

References

[1] Z. Demirel, 2004. The history and evaluation of saltwater intrusion into a coastal aquifer in Mersin, Turkey. J Environ Manage 70, 275-282.

[2] N. Phien-wej, P. H. Giao, P. Nutalaya, 2006. Land subsidence in Bangkok, Thailand. Engineering Geology 82, 187-201.

[3] R. Gonfiantini, M.-A. Roche, J.-C. Olivry, J.-C. Fontes, G. M. Zuppi, 2001. The altitude effect on the isotopic composition of tropical rains. Chemical Geology 181, 147-167.

[4] C. D. Cappa, 2003. Isotopic fractionation of water during evaporation. Journal of Geophysical Research 108.

[5] A. Angert, J.-E. Lee, D. A. N. Yakir, 2008. Seasonal variations in the isotopic composition of near-surface water vapour in the eastern Mediterranean. Tellus B 60, 674-684.

[6] J.-E. Lee, I. Fung, 2008. "Amount effect" of water isotopes and quantitative analysis of post-condensation processes. Hydrological Processes 22, 1-8.

[7] M. Katsuyama, T. Yoshioka, E. Konohira, 2015. Spatial distribution of oxygen-18 and deuterium in stream waters across the Ja-panese archipelago. Hydrology and Earth System Sciences 19, 1577-1588.

[8] Y. Tang *et al.*, 2015. Effects of changes in moisture source and the upstream rainout on stable isotopes in precipitation – a case study in Nanjing, eastern China. Hydrology and Earth System Sciences 19, 4293-4306.

[9] Wisittammasri, W., Chotpanrat, S., 2015. The survey on surface water condition in the area surrounding land of Chulalongkorn University, Kaeng Khoi district, Saraburi province. Environmental Journal 19 years, 54-65.

[10] Energy Policy and Planning Office, Ministry of Energy, Thailand. The monthly average temperature. http://www.e-report.energy.go.th/weather.html [2016 March 16].

[11] Hydrology Irrigation Center for Central Region, Royal Irrigation Department. Rainfall data. http://www.hydro5.com /in dex_. php?id=3 [2016 March 16].

[12] Noipow, N., 2015. Seasonal Variation of the Stable Isotope Fingerprints in daily precipitations and Mekong River, the implication on Hydrological Study of Thailand and Lao PDR., The 3 rd Lao-Thai Technical Conference, Bangkok, Thailand, 7-8 July 2015.

[13] N. Nunak, T. Suesut, 2012. Measurement and Instruments in the Food Industry, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, pp. 316.

[14] IAEA., Isotope Hydrology Information System. http://isohis.iaea.org [2016, March 16]

[15] Breitenbach, S. F. M., et al., 2010. Strong influence of water vapor source dynamics on stable isotopes in precipitation observed in Southern Meghalaya, NE India. Earth and Planetary Science Letters, 292, 212-220.

[16] Peng, H., Mayer, B., Harris, S., and Krouse, H. R., 2004. A 10-yr record of stable isotope ratios of hydrogen and oxygen in precipitation at Calgary, Alberta, Canada. Tellus B, 56, 147-159.

[17] Kamdee, K., et al., 2011. Improvement of Groundwater Modeling by Using of the Environmental Isotopes with Liquid Water Isotope Analyzer, The 12th Conference on Nuclear Science and Technology., Bangkok, Thailand, 6-7 July 2011.

[18] Clark, I. D., and Fritz, P., 1997. Environmental Isotopes in Hydrogeology, Lewis, Boca Raton.

[19] USGS. Resources on Isotopes. http://www.rcamnl.wr.usgs.gov/isoig/period/h_iig.html [2016 March 24].

[20] SAHRA. Isotope Oxygen. http://web.sahra.arizona.edu/programs/isotopes/oxygen.html [2016, March 24]

[21] Kamdee, K., et al., 2013. Use of isotope hydrology for groundwater resources study in Upper Chi river basin. Journal of Radio-analytical and Nuclear Chemistry, 297, 405-418.