การปรับปรุงแบบจำลองระบบน้ำบาดาลในแอ่งเชียงใหม่ด้วยเทคนิคไอโซโทป โดยเครื่องมือวิเคราะห์ไอโซโทปจากการดูดกลืนแสงเลเซอร์

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บทคัดย่อ

การวิเคราะห์ไอโซโทปเสถียรโดยการพัฒนาแนวคิดของวิเคราะห์แก๊สปริมาณน้อย ด้วยคุณลักษณะการดูดกลืนแสงเลเซอร์ (O'Keefe and Lee, 1989) สามารถนำมาประยุกต์ใช้ในการศึกษาไอโซโทปเสถียรในสิ่งแวดล้อมร่วมกับเทคนิคทางนิวเคลียร์อื่น แทนการวิเคราะห์ด้วยเครื่องมือ IRMS แบบเดิมได้เป็นอย่างดี ด้วยการวิเคราะห์ที่รวดเร็วและมีความยุ่งยากน้อยกว่า เทคนิคไอโซโทปดังกล่าวได้นำมาประยุกต์ใช้ในการศึกษาเพื่อปรับปรุงแนวทางการบริหารจัดการระบบน้ำบาดาลในพื้นที่แอ่งเชียงใหม่ซึ่งเป็นแอ่งระหว่างภูเขาอายุมหายุคซีโนโซอิกที่มีขนาดใหญ่ที่สุดในภาคเหนือของไทย ระบบน้ำบาดาลในพื้นที่ศึกษาสามารถแบ่งออกเป็นชั้นน้ำหลัก 3 ชั้น ได้แก่ชั้นน้ำเจ้าพระยา ชั้นน้ำเชียงราย และชั้นน้ำเชียงใหม่ ประกอบไปด้วยชั้นตะกอนร่วนและกึ่งร่วนของชั้นทรายและดินโคลนสลับชั้นกันแสดงลักษณะชั้นน้ำไม่มีแรงดันและมีแรงดัน ผลการวิเคราะห์องค์ประกอบทางเคมีและคุณภาพน้ำแสดงชุดลักษณะชนิดแคลเซียม-แมกนีเซียมไบคาร์บอเนต และชนิดโซเดียม-โพแทสเซียมไบคาร์บอเนต ซึ่งพบปัญหาปริมาณฟลูออไรด์สูงกว่ากำหนดค่ามาตรฐานน้ำดื่มในบางตัวอย่าง

ผลค่าอายุของน้ำบาดาลจากการวิเคราะห์ด้วยเทคนิคเรดิโอคาร์บอน พบว่าน้ำบาดาลมีอายุค่อนข้างมาก อยู่ระหว่าง 2,300 ±240 ถึงมากกว่า 30,000 ปี และมีปริมาณทริเทียมค่อนข้างต่ำน้อยกว่า 1.0 หน่วย (T.U.) ในตัวอย่างน้ำเกือบทั้งหมดยกเว้นน้ำบาดาลในบางตัวอย่างที่แสดงลักษณะการเติมน้ำจากน้ำผิวดิน ซึ่งจะมีปริมาณทริเทียมใกล้เคียงกับที่พบในน้ำผิวดิน อยู่ในช่วง 2.1-2.6 หน่วย (T.U.)

อัตราส่วนของไอโซโทปเสถียรจากเครื่องวิเคราะห์ไอโซโทปเสถียรในน้ำ (Los Gatos Research: DLT-100) แสดงลักษณะต้นกำเนิดของน้ำบาดาล มาจากการเติมน้ำเข้าสู่ระบบน้ำบาดาลโดยตรงจากน้ำฝนในระดับความสูงที่แตกต่างกันบริเวณลานตะพักระดับสูงใกล้กับขอบของแอ่งในบางบริเวณที่เป็นพื้นที่เติมน้ำ มากกว่าการไหลลงสู่ระบบของน้ำผิวดินจากน้ำท่าและน้ำจากแหล่งกักเก็บน้ำต่าง ๆ ผลค่าอายุของไอโซโทปรังสี ไม่แสดงการแยกชั้นอย่างชัดเจนของน้ำบาดาลในชั้นน้ำระดับลึกและตื้น คล้ายกับผลการศึกษาในปี พ.ศ. 2536 (Buapheng et al., 1993). แต่ผลการศึกษาโดยละเอียดในปัจจุบัน แสดงถึงลักษณะการไหลผสมกันของน้ำเก่าในชั้นน้ำบาดาลในอัตราที่ค่อนข้างช้า และกรอบแนวคิดของแบบจำลองระบบน้ำบาดาลในแอ่งเชียงใหม่ควรมีการปรับปรุง โดยเพิ่มลักษณะการเติมน้ำในพื้นที่เติมน้ำบริเวณลานตะพักระดับสูง ซึ่งมีการเติมเข้าไปโดยตรงในชั้นน้ำระดับลึกในอัตราที่รวดเร็วกว่า ซึ่งการปรับกรอบแนวความคิดดังกล่าวจะมีผลต่อการคำนวณทิศทางและอัตราการไหลของน้ำบาดาลในระบบให้ตรงกับความเป็นจริงมากยิ่งขึ้น และเป็นแนวทางในการเสนอแนวทางในการบริหารจัดการทรัพยากรน้ำในพื้นที่เพื่อความยั่งยืนต่อไปในอนาคต

คำสำคัญ : น้ำบาดาล ไอโซโทปเสถียร แอ่งเชียงใหม่ การดูดกลืนแสงเลเซอร์

Improvement of Groundwater Modeling by Using of the Environmental Isotopes with Liquid Water Isotope Analyzer

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Abstract

A new analysis method of stable isotope was developed by using the absorption characteristic of pulsed laser beam concept for trace gas analysis (O'Keefe, 1989). The method provides high performance and analysis capacity but contribute less applicative compared to the traditional IRMS methods by using only pure liquids phase of water. The methods are using with environmental isotopes techniques to improve groundwater management of the Chiang Mai Basin, the biggest Cenozoic basin in the northern part of Thailand.

Unconsolidated and consolidated sediments form three main aquifers, the Chao Phraya, Chiang Rai and Chiang Mai Aquifers, show clearly unconfined to confined characteristic. From chemical composition of the groundwater, most of groundwater samples are of calcium-magnesium bicarbonate and sodium-potassium bicarbonate type and few of them show the risk of fluorine content for drinking purpose.

Radioactive Carbon results showed the ages of groundwater vary from 2,300 ±240 to +30,000 years. The tritium results showed low tritium content, less than 1.0 Tritium Unit (T.U.) in all groundwater samples, was compared to the surface water that arranged from 2.1-2.6 T.U.

The stable isotope result of the liquid water isotope analyzer (Los Gatos Research: DLT-100) indicated the main recharge resources of groundwater in the basin was from the local rain water in terrace area and from both sides of the basin at different altitudes. Surface water from rivers and dams have no contribution to the origin of groundwater in the basin. The radioactive and stable isotope data of ground water from different aquifers did not show clear separation and was similar to the previous study of the basin in 1993 (Buapheng et al., 1993). Thus, the recent data accrue to be convinced that there was some mixing of groundwater within three aquifers and rather slow replenishment. The conceptual modeling of groundwater system in Chiang Mai Basin can be revised. The Upper part of Chiang Mai Aquifers that patchy exposed in the high terrace were identified as main recharge areas that the younger water could be recharged directly to the deeper aquifers.

Keywords: groundwater, stable isotope, Chiang Mai basin, laser absorption

1. Introduction

Chiang Mai Basin is the biggest Cenozoic intermontane basin in the northern part of Thailand. The large plain inside the basin is fertile area which locates the Chiang Mai metropolis, the second biggest city in Thailand. The beautiful mountainous areas surrounding the basin as well as wonderful culture are attracted by tourism causes the population increased rapidly during the past two decades. The heavy pumping of groundwater for agriculture and urban water supply in this area has already caused groundwater depletions in some areas. Isotope technique for groundwater management project with a collaboration of Thailand Institute of Nuclear Technology (TINT) and Department of Groundwater Resource (DGR) was setup to improve the groundwater management in this area.

2. Geography and Hydrogeology

2.1 Geography

The Chiang Mai basin is a structural basin resulting from tectonic evolution in the Tertiary period. The basin was formed by east-west extension, and has a kidney-like shape about 150 km. from the north to south and about 45 km. at the maximum width covers area of 5,000 km^2. The eastern and northern boundaries are bounded mainly by mountain ranges. Inside the basin, there are two main attributes namely Mae Ping and Kuang River (Fig. 1). The Mae Ping River flows through the basin from north to south in the centre and divides the basin into east and west parts, the Kuang River entering the basin at north-east and then flows parallel to Ping River before the rivers join at the southern part of the study area. The rivers form narrow flood plain deposits on the both sides of river banks which average elevation is about 300 meters above mean sea level (m.asl.). Alluvial fans were occurred at both sides where many tributaries drain water from the marginal watersheds into the basin. The biggest fan is the Mae Kuang Alluvial fan in the north-eastern part.

The Terraces formed along its margin at altitudes from 320 to 450 m.asl. Terraces were built up by the ancient Ping River in both sides of the basin. The terraces are divided into high terraces and low terraces by their elevations. The high terraces occurred at the outer rim of the basin an elevation between 330 and 450 m.asl. which the terraces in the western part are higher than in the eastern part. The low terraces are separated from the high terraces by geomorphology, land uses and their elevations which range from 300 to 330 m.asl.

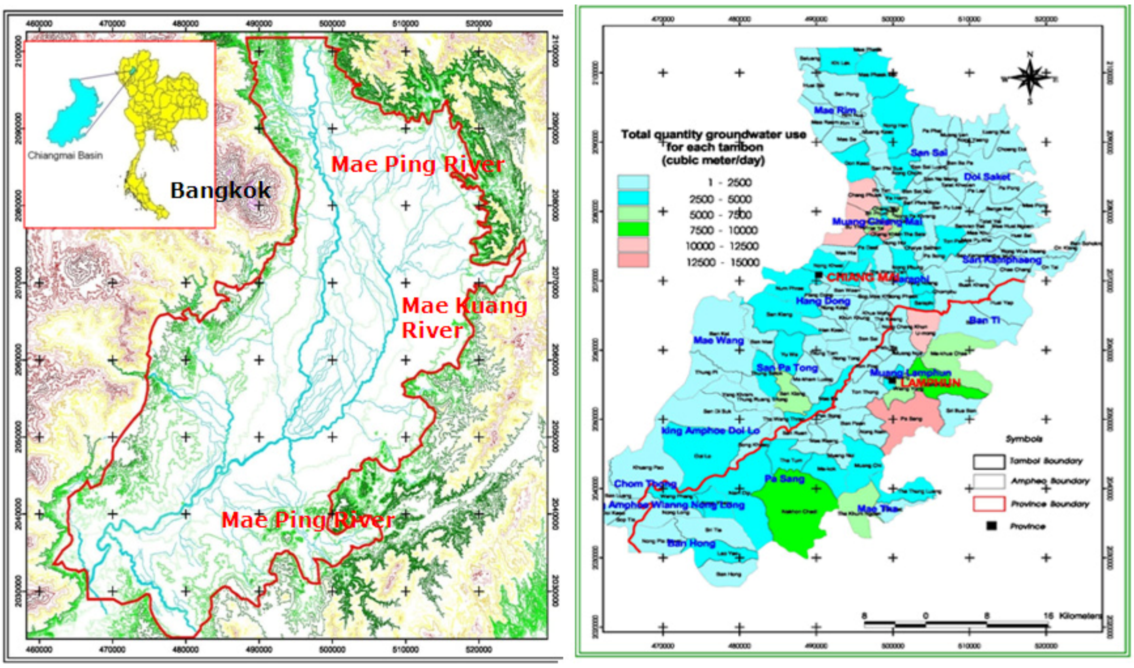

Fig. 1 Geographical map of the study area shows main river attributes, hydrological basin boundary and the usage of groundwater supply.

2.2 Hydrogeology

The aquifer system in the Chiang Mai basin consists mainly of unconsolidated sediments. Consolidated rocks of Precambrian and Lower Paleozoic metasedimentary rocks, volcanic and granitic rocks underlie the groundwater basin and exposed in the periphery. (Fig. 2) These rocks are less productive to non-productive in terms of groundwater yield, except the limestone. The unconsolidated to semi-consolidated sediments consist of clay, silt, sand and gravels of Upper Tertiary to Quaternary period. The total thickness of deposits varies from 915 to 1,370 m. (Buapeng et al., 1993)[1] and can be divided into two zones according their lithologic compaction. The upper zone consists of unconsolidated sediments of floodplain and younger terrace deposits formed two main aquifers namely Chao Phraya Aquifers and Chiang Rai Aquifers.

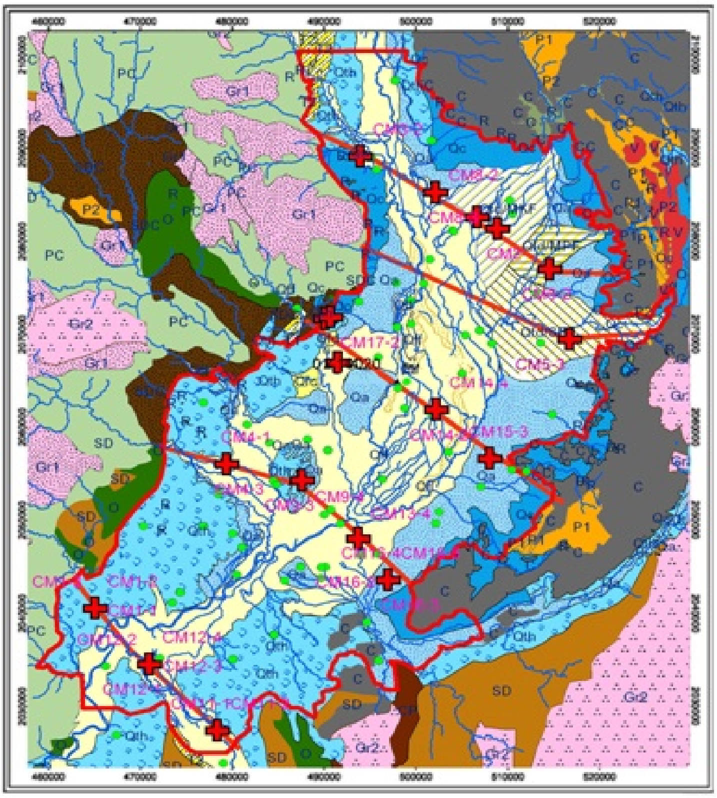

Fig. 2 Geological map of the Chiang Mai Basin shows hydrological units, sampling line concept and the location of groundwater sampling points.

- Chao Phraya Aquifers (Alluvium, Qfd/Q_{CPY}) compose of recent alluvial sediments on the flood plain area in the central part. The thickness of the aquifer ranges from 20-60 m. These aquifers are productive, yielding up to 50 m^3/hr. Transmissivity ranges from 42 to 3,430 m^2/d.

- Chiang Rai Aquifers (Qa/Q_{CR}) exposed as younger terrace deposits. They are recognized as flat areas between the flood plain and the rolling hill areas of high terrace. The sediments comprise of a thick sequence of clay and variety of clastic fragments. Maximum thickness is 75 m. and separated by thick confining clay into two subaquifers. The aquifer relatively less productive, rarely yield more than 10 m^3/hr, maximum transmissivity of 385 m^2/d. (Chuamthaisong, 1971)[2]

The lower zone consists of semi-consolidated sediments of older terraces deposits formed the aquifer namely Chiang Mai Aquifers.

- Chiang Mai Aquifers (Qth/Q_{CM}) are recognized as older terrace deposits, exposed along the basin margin, especially in the western part. Most parts of the aquifers are concealed under the Chiang Rai Aquifers. The maximum depth to the top of the aquifers is 150 m. below ground surface. The aquifers are composed of sand and gravel layers and considered to be the most productive with yields of 100 to 200 m^3/hr. The maximum transmissivity of 1,200 m^2/d can be obtained.

3. Methodology

The environmental isotope techniques can be applied as tools to determine the origin of groundwater, the interaction of "the waters" in hydrological system, groundwater movement and its velocity, the replenishment rate and the age of groundwater in different aquifers. This valuable information in conjunction with hydrological and chemical data including well defined groundwater modeling can inform the ground water assessment point of view and the groundwater management in the study area can be improved.

3.1 Field investigation and sampling concept

Many water samples from groundwater, rivers and reservoirs including local precipitation in Chiang Mai basin were collected for analyses isotopes and chemical constituents. The first set of samples was collected on March 2007 represents the dry season and on August 2008 represents the rainy season from 36 of monitoring wells in systematic sampling line disseminates in depths and aquifers. The surface water samples were represented by 6 samples from river, and 3 samples from Mae Kuang dam. The physico-chemical parameters like EC, pH, TDS, Eh and temperature were measured in the field.

3.2 Isotope Techniques

Environmental isotopes have become a routine component of hydrogeology, complementing geochemistry and physical hydrogeology in groundwater resource and groundwater contaminant studies. The water samples in this research were analyzed for $\delta^{2}H$, $\delta^{18}O$, ^{3}H, ^{14}C and major chemical ions. Decay of radioisotopes provides us with a measure of circulation time, and thus groundwater renewability. The tritium contents were analyzed by Liquid Scintillation Counter (Quantulus 1220) after electrolytic enrichment at Thailand Institute of Nuclear Technology. For radiocarbon dating, they were analyzed by Liquid Scintillation Counter (Quantulus 1220) after direct CO_2 absorption. In part of major chemical, the water samples were carried out at the Department of Groundwater Resources Laboratory.

Meteorological processes modify the stable isotopic composition of water, giving recharge waters in a particular environment a characteristic isotopic signature. This signature then serves as a natural tracer for the provenance of groundwater. Stable isotopes ratio in water, solutes and solids tells us about groundwater quality, geochemical evolution, recharge processes, rock-water interaction, origin of groundwater samples and contaminant processes. The $\delta^{2}H$ and $\delta^{18}O$ in water samples were analyzed by Liquid Water Isotope Analyzer at Thailand Institute of Nuclear Technology.

3.3 Liquid Water Isotope Analyzer

Stable isotope ratios of hydrogen and oxygen in natural waters (δ^2H and δ^{18}O) are effective tracers of the terrestrial water cycle and provide advantageous insights into hydrological, climatic, and ecological processes at all scales. A spectroscopic instrument, LGR DLT-100, measures laser absorption within a capacity with high-reflectivity mirrors to generate path lengths of several kilometers resulting in clear separation of laser absorption line of different water molecules. The method provides high performance and analysis capacity compared to the convention IRMS methods but comparisons between results from the laser instrument and IRMS are presented using the internationally accepted VSMOW-SLAP scale.

Analytical method base on Beer's Law, when a laser beam is directed through water vapour, the mixing ration (or mole fraction) χ is related to measure absorption according:

$$\frac{I_v}{I_o} = e^{-SL\chi P \text{Ø}_v}$$

Where I_v is the transmitted laser intensity through the sample at frequency v; I_o is the intensity before entering the cell; P is gas pressure; S is absorption line strength; Ø_v is the transition lineshape function (with $\int \text{Ø}_v \, dv \equiv 1$), and L is the optical path length (O'Keefe and Lee, 1989)[3].

Thus, the absolute abundance of individual molecules can be quantified though the amount of absorbance at a specific wavelength. The instrument measures absorption around a wavelength of 1390 nm. to calculate molecular concentrations of ^{2}H HO, HH ^{18}O and HHO and be converted into atomic ratios, ^{2}H/^{1}H and ^{18}O/^{16}O and a post-processing procedure is used to calculate delta-scale (δ) value with respect to Vienna Standard Mean Ocean Water (VSMOW):

$$\delta = \frac{R_{measured} - R_{VSMOW}}{R_{VSMOW}}$$

where R is ^{2}H/^{1}H or ^{18}O/^{16}O (Coplen, 1996)[4]

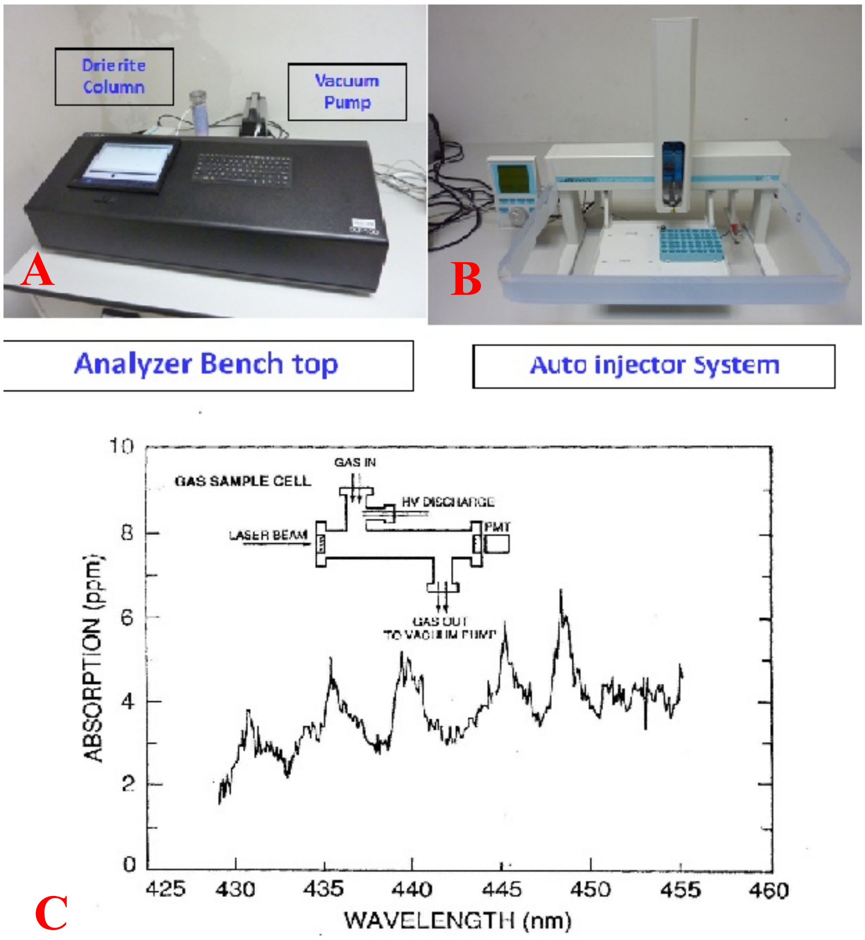

Fig. 3 Liquid Water Isotope Analyzer details showing the analyzer bench top compartment (A), the auto ejector compartment (B) and the analyze concept diagram with laser absorption characteristic from O'Keefe and Lee, 1989 (C).

4. Results and Discussions

4.1 Hydrochemical characteristics

The quality of the groundwater in the basin is relatively in some chemical constituents. Fluoride is over the maximum acceptable level by the WHO Drinking Water Standards. It has problem to quality of groundwater in some areas of Lamphun and Chiang Mai provinces.

Its content in the groundwater samples collected from wells in Muaeng district, Lamphun province, was reported to be as high as 13.0 mg/l. The results of chemical analysis of groundwater and surface water show that most of waters are of calcium-magnesium bicarbonate and sodium-potassium bicarbonate type. The graphical representations of the water quality using the Piper diagram (Figure 4)

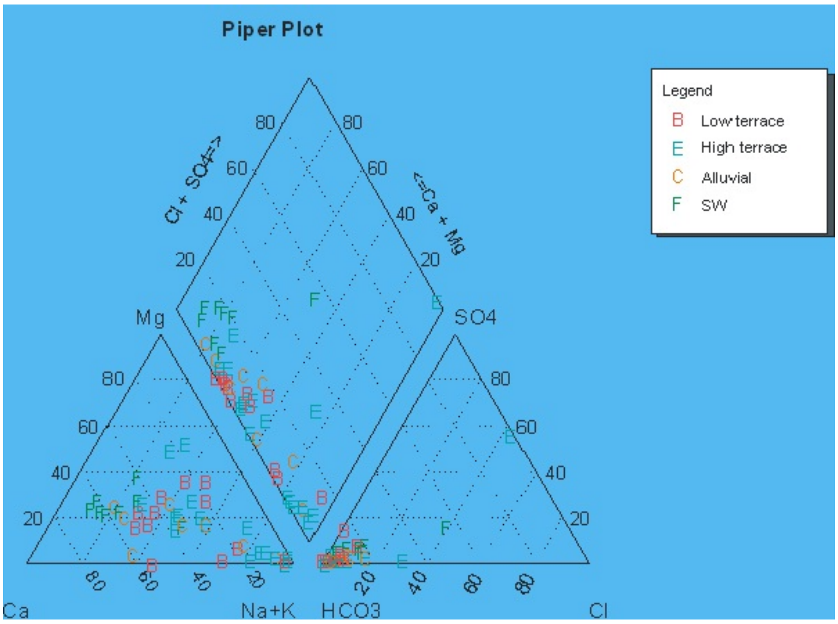

Fig. 4 Piper diagram of the chemical composition in groundwater and surface water samples showing the chemical facies types of calcium-magnesium bicarbonate and sodium-potassium bicarbonate type.

4.2 Radioisotopes characteristics

Radioactive Carbon results of the groundwater in deep to moderate depth borehole wells from Chiang Rai Aquifers (Q_{CR}) and Chiang Mai Aquifers showed abundance of ancient water characteristic. The ages of groundwater vary from 2,300 ±240 to +30,000 years. In prospect recharge area, the moderate depth groundwater from upper subaquifers of Chiang Mai Aquifers (Qcm1 and Qcm2) implied mixture characteristic of young water and ancient water that the age were identified less than 1,500 years (CM10-2, CM10-3 and CM3-2).

The tritium results showed low tritium content, less than 1.0 Tritium Unit (T.U.) in all groundwater samples except some shallow wells near a revelation of older terrace (CM4-2 and CM4-3). The higher tritium content (>2.0 T.U.) were found and it can be compared to the tritium content in surface water that arranged from 2.1-2.6 T.U.

4.3 Stable isotopes characteristics

The δ^{2}H and δ^{18}O values will be interpreted with comparing to the local meteoric water line (LMWL). The Bangkok local meteoric water line (Bangkok LMWL) that was measured during 1968-1987 following equation:

$$\delta^2H = 7.67\ \delta^{18}O + 6.88$$

The precipitation in Chiang Mai quite resemble to the Bangkok LMWL they represent by the equation:

$$\delta^2H = 7.8597\ \delta^{18}O + 7.2723$$

The equation show difference in climatic condition with slightly higher slope expresses more arid vapour source. The isotopic access point of average rainfall in all season expresses cooler or higher attitude characteristic.

The δ^2H and $\delta^{18}O$ values of the samples are plotted with the relationship to the LMWL shows in figure 5.

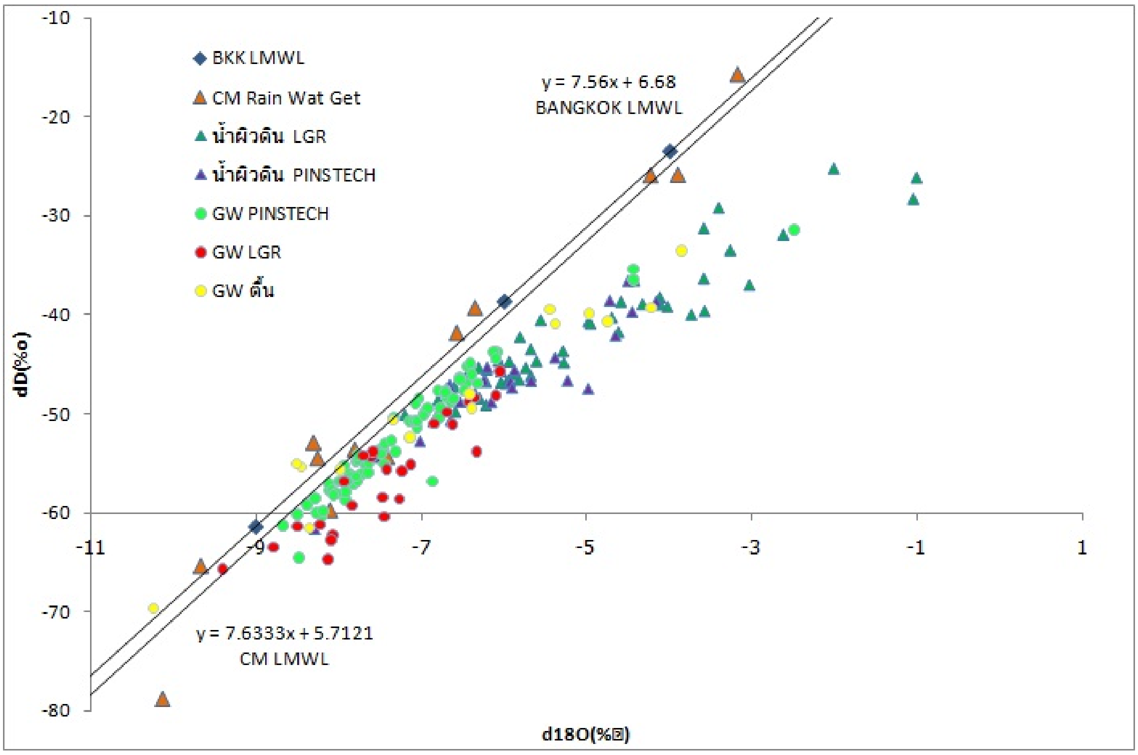

Fig. 5 The relationship between δ^2H and $\delta^{18}O$ showing the local meteoric water line (LMWL) in Chaingmai Basin comparing with the Bangkok LMWL and the distribution of isotope characteristics in the studying water samples.

The stable isotope result shows evaporation effect in the surface water but the interaction to the groundwater occurred in few localities. The samples from well numbers CM10-3, CM6-5, CM10-2, CM6-2 and CM5-2 probably site in recharge area with stable isotope characteristic are resemble with the surface water samples.

The groundwater should be mainly originated from the local rainfall at the different altitude and locally recharged and mixed with the old groundwater in different layers and depths. The main recharge area where the new replenishment water accessed to the groundwater system locate in the high terrace area near the Mae Khan, Mae Sa and Mae Rim river valleys.

5. Summary

The radioactive and stable isotope data of ground water from different aquifers did not show clear separation and was similar to the previous study of the basin in 1993 (Buapheng et al., 1993). Thus, the recent data accrue to be convinced that there was some mixing of groundwater within three aquifers and rather slow replenishment.

The conceptual modeling of groundwater system in Chiang Mai Basin can be revised (Figure 6). The Upper part of Chiang Mai Aquifers that patchy exposed in the high terraces were identified as main recharge areas that the younger water could be recharged directly to the deeper aquifers.

The conceptual model modification and the basis information resulted in this study will advantage to the further tasks on modeling calibration, water budget balance and the medium-local scale research including the groundwater assessment in the future.

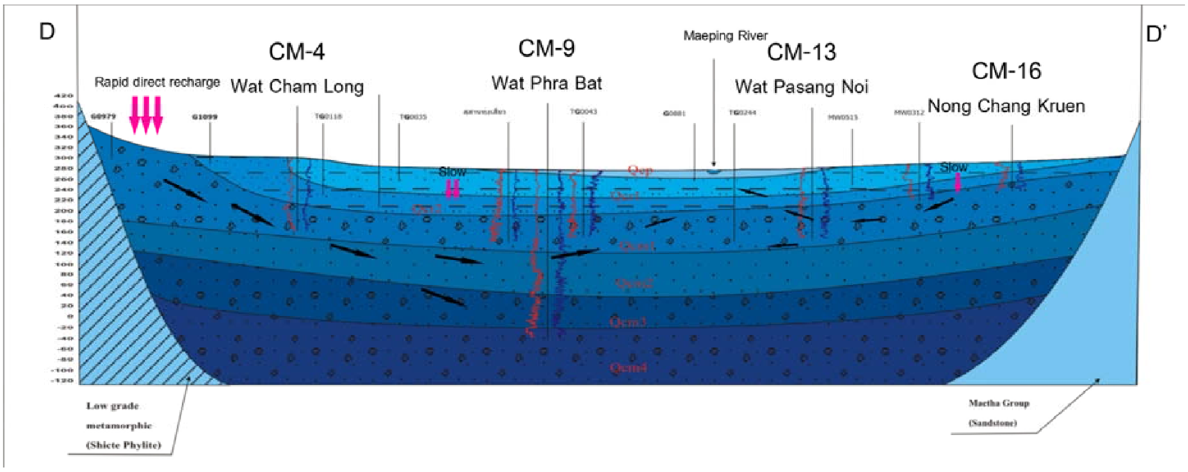

Fig. 6 The geologic cross-section is showing the revision conceptual model using the application of isotope information.

6. Acknowledgments

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