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Hydrochemical and Isotopic Characteristics of Groundwater in the Lampang Basin, Northern Thailand

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ABSTRACT: Analyses of hydrochemical and stable hydrogen and oxygen isotopes, ^{2}H and ^{18}O, were conducted on 76 water samples collected during September and October, 1997, and during January and December, 2002. The set included 10 rainwater samples, 16 river water samples, 2 surface water samples, and 48 groundwater samples, all within the Lampang basin. The analyses were done to document the chemical and isotopic characters of the natural waters, and to determine the origin of groundwater in three different aquifer units. These aquifer units are Holocene unconsolidated sediments, Pleistocene unconsolidated sediments, and Tertiary consolidated and semi-consolidated sediments. Hydrochemical data are classified on the basis of dominant ions by mean of Piper-trilinear diagram as hydrochemical facies. All the groundwater samples from the three aquifer units are similar in hydrochemical facies. This indicates that all of the groundwater is recharged by chemically similar waters, i.e., the groundwater is infiltrated by the same source of recharge water. It was not possible to define a meteoric water baseline for the Lampang basin. So, the meteoric water baseline for Thailand, $\delta D = 7.35\ \delta^{18}O + 6.11$, $R^2=0.972$, was adopted as the Lampang basin meteoric water baseline. Isotopic analyses of groundwater from the three aquifer units are not significantly different in their δD-$\delta^{18}O$ and are very similar to local precipitation. This suggests that all of the groundwater in the system is recharged by isotopically similar water from local precipitation and from infiltration water that is not fractionated during passage through the aquifers. Equally, there is little or no effect from interactions between the water and rocks. The isotopic composition of the river water samples is enriched in heavy isotopes relative to the groundwater samples. The possible explanation for this is, that the river water may be derived from groundwaters that have been mixed with water derived from dams.

KEYWORDS: hydrochemical, groundwater origin, stable isotope, aquifer, meteoric water baseline

INTRODUCTION

Groundwater is an important source of water supply in the Lampang basin. It is mainly developed for domestic and industrial uses because there is insufficient surface water. The population and industrial development of the basin are increasing. Large-scale groundwater abstraction in the area has resulted in adverse economic and environmental problems, such as declining piezometric levels and deterioration in groundwater quality. These problems will become more serious in the future. Management of the groundwater resources requires an understanding of the main processes controlling the geochemical evolution and origin of exploited groundwater.

The chemical characteristics of the groundwater provide clues to its geological history, its influence on the soil or rock masses through which it has passed, and its mode of origin within the hydrogeologic cycle.[1,2,3] Isotopic characteristics and the origin of the groundwater can be evaluated from stable isotopic abundance and variations in the abundance of the isotopes ^{2}H and ^{18}O. The conservative nature of the stable isotopic composition of water in an aquifer makes it possible to characterize the origin and recharge of the water.[4] The application of the environmental isotope method to recharge problems is based on the spatial and temporal variability of the isotopic content of water. The spatial variability is related mainly to four different issues: the effects of altitude, latitude, the season, and any fractionation related to the water's history.[5] In a groundwater basin where barrier boundaries and inputs are well defined, interpretation of the environmental isotope record of precipitation, and surface- and ground-water, coupled with available information on hydrochemical characteristics, stream flow and groundwater levels will provide a detailed picture of the groundwater system in the basin.[6,7,8,9,10]

The purpose of this study was to document the chemical and isotopic characteristics of water to determine the origin of groundwater and the hydrologic relations between precipitation, and surface, and ground-water from different aquifer units in the Lampang basin. These units were the unconsolidated sediments of the Holocene (Qa) and Pleistocene (Qt) and consolidated and semi-consolidated sediments of Tertiary (T). The study was designed to

1) develop a database of the hydrochemical and the isotopic composition (^{2}H and ^{18}O) of precipitation, surface water, and groundwater in the basin,
2) assess the origin of groundwater and influence of seasonal precipitation on recharge to aquifer, and
3) assess the interaction between the groundwater and surface water.

Description of the Study Area

The Lampang basin is an intermontane basin that resulted from tectonic evolution during the Tertiary Period.[11,12] It is elongated and trends approximately north-south, covering about 850 square kilometers (Fig 1). The western and northern regions of the basin are bounded by mountain ranges underlain mainly by Silurian and Devonian metamorphic rocks, Carboniferous metasedimentary rocks, Permian clastic and volcanic rocks, and Triassic granitic rocks. The basin's eastern region is bounded mainly by mountain ranges of Permian volcanic rocks and its southern region is bounded by Pleistocene basalt.

The catchment of the basin has a seasonal tropical climate and a mean annual precipitation of 1,100 millimeters. A distinct dry season occurs from November to April and 90% of the precipitation falls during the wet season from May to October. The mean annual temperature is 25.8 °C, with daily highs of 30 °C throughout the year and 36 °C in the hot dry months from February to May. Average pan evaporation is about 130 millimeters in the dry season and about 115 millimeters in the wet season for the period from 1972 to 2002.[13]

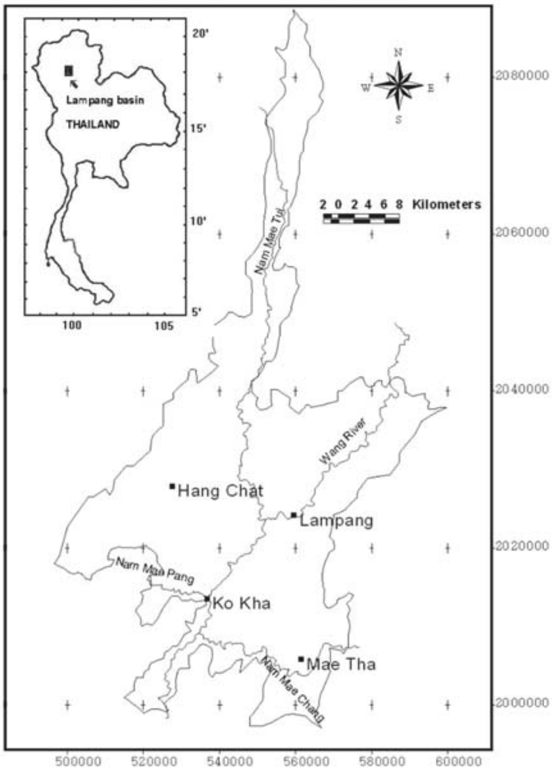

Fig 1. Location map of the Lampang basin.

The hill and mountain area of the catchment is mostly at elevations between 300 and 600 meters, while the basin has an average elevation of 240 meters, ranging from 220 to 280 meters. The catchment was formerly covered by deciduous forests but its low lands were cleared many centuries ago for paddy rice farming and extensive logging for teak occurred early in the 19^{th} century. The principal streams are the Wang and Tui Rivers.

Geological and Hydrogeological Setting

The Lampang basin was formed by faulting and subsidence in the Late Cenozoic, and its sedimentary fill is about 300 meters thick. The surrounding mountains and underlying basement rocks are well-indurated metasedimentary and intrusive rocks of pre-Tertiary age, although some Tertiary limestone occurs in the eastern part of the basin. These rocks have low potential as aquifers. Deep weathering and saprolite seal them from major groundwater infiltration and they were, therefore, ignored in this study.

The Late Cenozoic sediments considered to be significant aquifers are the Tertiary sediments, Pleistocene terrace deposits, and Holocene floodplain and channel deposits. These units are described in Fig 2 and Table 1. The depth from the surface to the

Table 1. Summary of the aquifers in the Lampang basin.

Hydrogeologic formation	Aquifer unit	Lithology	Average depth(m)	Yield (m^3/day)	Transmissivity (m^2/day)
Quaternary Holocene	Qa	- Meandering belt subunit: sand, light gray, light brown, interbedded with gray clay layer. - Natural levee silt sub unit: silt, very fine sand, light brown, micaceous, overlies thick-bedded clay. - Alluvial fan sand and clay subunit: sand, clayey and silty, light gray, interbedded with sandy clay. - Fluvial clay subunit: clay, gray, silt, clay and mud.	9-80	40-1,300	2-625
Quaternary Pleistocene	Qt	- Terrace deposits, coarse fluvialtile sediments that fill gravel beds, sand, silt, and clay, with thick layer of laterite.	6-120	60-960	1-250
Tertiary Upper	T	- Unconsolidated and semi-consolidated sediments, sandy clay, clayey sand, gravelly sand and gravel, shale, siltstone, sandstone, mudstone, and diatomaceous shale.	18-190	50-250	1-33

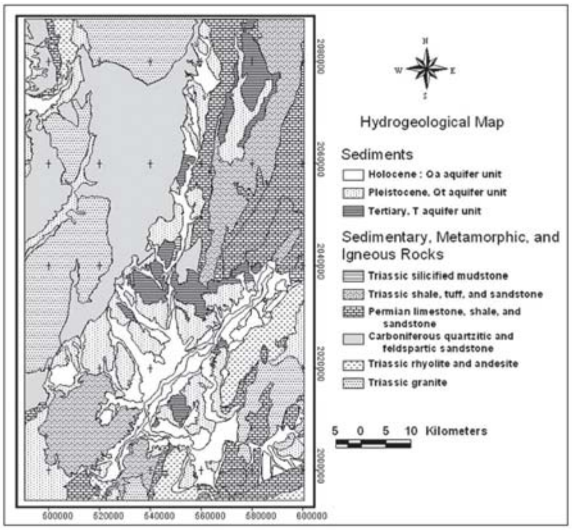

Fig 2. Hydrogeological map of the Lampang basin.

groundwater level generally ranges from a few meters in the inner parts of the basin to 25 meters along the basin periphery. Groundwater movement is mainly controlled by the topography and flow from north to south that is combined with movement from the basin periphery to its central axis.

Materials and Methods

Determinations of water chemistry and the stable hydrogen and oxygen isotopes, ^{2}H and ^{18}O, were conducted on 44 water samples collected during September and October, 1997, and on 32 samples collected during January and December, 2002. The samples from 1997 included three of rain-water, 10 of river water, and 31 of groundwater. Those from 2002 included seven of rainwater, 8 of river water, and 17 of groundwater. The sampling locations are shown in Fig 3 and results of the chemical analyses and the isotopic compositions of the waters are shown in Table 2.

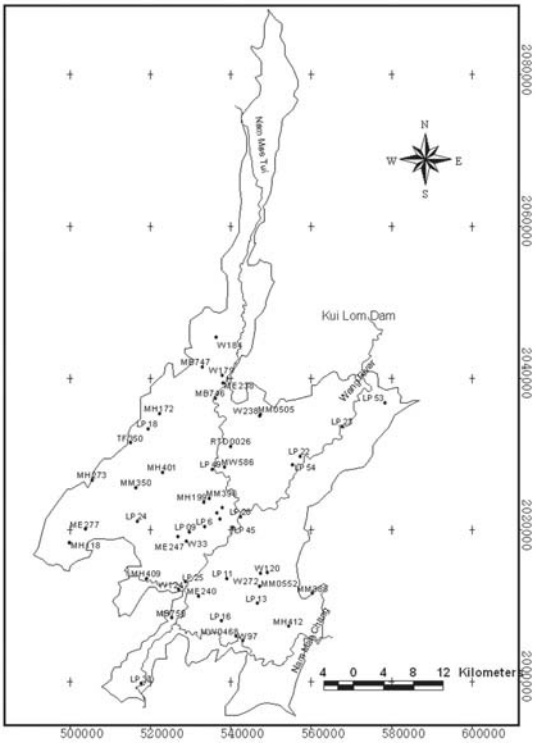

Fig 3. Location of water samples for chemical and isotopic analyses.

Table 2. Chemical analyses and stable isotopic composition of water in the Lampang basin.

Sample no.	Aquifer unit	Time	Depth (m)	TDS (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^{+} (mg/l)	K^{+} (mg/l)	Fe (mg/l)	Mn (mg/l)	Cl (mg/l)	SO4 ² (mg/l)	CO3 ² (mg/l)	HCO3 (mg/l)	NO3 (mg/l)	F (mg/l)	δ18O (‰)	δD (‰)
Groundwater sample																		
ME0240	Qa	Sept- Oct	43-55	1,260	25	9	173	15	0.62	0.01	45	75	0	164	0.7	1.2	-8.15	-59.7
W33	Qa	1997	61-69	228	26	27	23	4.7	6	0.2	7	2	19	235	1.1	0	-6.71	-52.3
W97	Qa		6-18	604	66	40	90	2.3	0.01	0	51	93	0	400	47	0.3	-9.28	-72.3
W179	Qa		37-48	44	35	3	1	14	21	0.11	2	2	0	129	0.4	0.1	-7.88	-58.5
MM388	Qa		37-43	398	43	34	39	3.1	1.2	0	6	120	0	232	0.7	0.1	-7.83	-57.6
MB758	Qa		12-18	346	51	13	60	4.7	4.1	1.5	14	34	0	315	3	0.7	-6.54	-54.2
MH118	Qa		12-18	150	43	4	7	5.1	2.3	0.34	2	3	0	164	0	0.6	-7.38	-57.1
W172	Qa		12-24	1,040	52	29	110	68	0.25	0.03	40	93	0	395	76	0.4	-7.01	-55.4
MH199	Qa		43-55	160	11	12	30	4.7	5	0	7	5	0	150	0	0.1	-7.56	-57.7
MH273	Qa		24-30	468	10	4	170	3.5	0.62	0	5	3	36	372	4	8.8	-7.34	-56.9
MW586	Qa		12-18	62	27	3	8	1.8	18	0.99	12	2	0	91	0	0.1	-5.67	-48.1
LP6	Qa		72-84	278	8	3	85	5.1	1.2	0.16	5	4	0	286	0	0.2	-7.72	-59.5
LP17	Qa		18-22	494	12	6	160	5.1	0.26	0	4	3	0	477	1.2	1.3	-6.35	-52.6
ME238	Qa		55-67	200	5	1	46	3.5	14	0	5	5	16	113	0.2	0.4	-7.59	-56.9
ME247	Qt		116-122	278	7	8	110	4	20	0.01	10	3.4	26	272	0.2	1.2	-6.49	-51.6
ME277	Qt		64-76	432	8	2	174	2.4	2.6	0.01	9	4.5	0	448	7.5	9.3	-7.75	-58.1
W120	Qt		24-40	144	7	5	30	4.7	3.8	0.2	5	3.3	0	123	0	0.3	-7.43	-59.8
W184	Qt		49-55	51	6	6	2	6.6	5.5	0.51	3	2	0	61	0.1	0.2	-7.95	-55.8
W238	Qt		52-58	190	7	6	56	6.1	0.76	0.17	6	21	0	201	0.2	0.2	-7.69	-58.2
MM350	Qt		43-49	129	20	7	9	11	0.36	0	2	1	30	48	0	0.2	-7.68	-56.8
MM396	Qt		82-91	244	39	19	14	6.6	0.6	0	2	3	0	205	4.2	0.2	-7.39	-60.7
MH401	Qt		55-67	320	37	3	46	9	6	0.16	2	4	0	250	0	0.2	-6.91	-54.6
MH409	Qt		49-55	216	57	4	18	2	20	0.13	6	8	6	218	0	0.3	-6.04	-49.9
LP22	Qt		64-68	263	25	6	42	9.8	1	0	0	0	3	172	0	0.3	-7.06	-53.3
W124	T		30-60	1,248	21	71	190	11	1.2	0	1	245	0	90	0	1	-6.94	-55.8
W272	T		52-58	484	26	6	130	2.9	0.76	0.01	3	3	0	428	17	0.1	-7.98	-62.7
ME746	T		43-49	536	47	7	32	6.8	12	0.03	4.3	50	0	245	0.7	0.4	-6.24	-49.6
MB747	T		30-37	360	33	12	81	0.9	2	0.55	21	24	0	303	2.3	0.5	-7.56	-55.3
MH172	T		79-91	474	7	5	156	2	0.13	0.03	3	14	0	479	0	3.8	-6.12	-48.3
MH412	T		15-21	50	3	4	21	5.9	1.9	0.16	16	5	0	49	1.7	0	-7.06	-56
LP28	T		92-98	374	3	5	110	5	1.5	0.01	3	3	0	282	6.4	0.2	-7.79	-60.4
LP54	Qa	Jan-Dec	8-16	432	18	61	32	12	0.31	0.14	17	11	0	398	0.3	0.2	-5.04	-39.9
LP46	Qa	2002	24-32	126	13	2	18	4.7	0.38	0.01	2	2	0	93	1.2	0.1	-5.79	-45.6
LP25	Qa		40-48	314	19	11	45	10	22	0.75	6	38	0	189	1.2	0	-6.98	-47.4
LP45	Qa		8-16	278	18	3	90	3.6	1.7	0.11	3	3	1	293	0	0.7	-6.41	-48.6
LP18	Qa		24-30	224	47	3	5	5.5	0.52	0.13	1	2	0	162	0.2	0.1	-6.01	-44.4
LP49	Qa		54-58	202	27	10	12	3.1	5.6	0	4	3	0	161	0.4	0.2	-7.34	-53.9
LP23	Qt		72-78	236	31	20	14	3.5	1.6	0.07	16	29	17	123	0	0.1	-7.72	-56.1
LP53	Qt		32-44	176	20	1	51	1.2	0.03	0.15	11	4	0	153	4.7	0.3	-6.66	-47.3

Table 2. *Cont'd.*

Sample no.	Aquifer unit	Time	Depth (m)	TDS (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^{+} (mg/l)	K^{+} (mg/l)	Fe (mg/l)	Mn (mg/l)	Cl (mg/l)	$SO4^{2}$ (mg/l)	$CO3^{2}$ (mg/l)	HCO3 (mg/l)	NO3 (mg/l)	F (mg/l)	δ18O (‰)	δD (‰)
MM0505	Qt		54-60	164	13	6	28	7.8	4.8	0	3	3	0	140	0.2	0.1	-7.58	-53
MM0552	Qt		36-40	280	18	4	80	6.3	0.72	0	1	2	0	273	0	5.3	-6.68	-50
MW0468	Qt		43-49	584	81	25	69	5.1	0.76	0.15	25	80	0	330	36	0.4	-6.38	-47.9
LP16	Qt		60-68	274	8	3	83	5.1	1.2	0.19	5	4.5	0	286	0	0.2	-9.92	-71.2
LP13	Qt		54-60	290	37	5	65	4.1	5.8	0.01	5	1.5	0	312	0.3	0.2	-7.34	-55.2
LP37	Qt		90-102	316	17	2	83	2	1.4	0.06	4	2	0	298	17	0.2	-6.8	-52.1
TF0350	Qt		9-10	220	76	8	39	0.4	0.58	0	15	21	0	263	0.1	0.3	-7.04	-51.1
LP11	T		190-202	322	5	3	97	10	0.9	0.02	6	2	0	284	3	0.3	-56.8	-8.01
LP24	T		78-84	370	10	4	88	7.8	1.3	0	6	2.2	0	286	0	0.3	-53	-8.44
Rain water																		
P1	-	25-Sep-97	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-11.07	-81
P2	-	2-Oct-97	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-7.48	-56.8
P3	-	28-Oct-97	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-11.42	-85.5
P4	-	17-Jan-02	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-6.58	-45.3
P5	-	12-Apr-02	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-5.43	-33.6
P6	-	6-May-02	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-5.8	-41.6
P7	-	2-Jun-02	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-7.27	-51.6
P8	-	16-Jul-02	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-6.45	-45.9
P9	-	2-Sep-02	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-8.67	-62.4
P10	-	6-Oct-02	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-7.96	-61
Surface water																		
R1	Nam Mae San	27-Oct-97	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-5.79	-48.1
R2	Nam Mae Bon	27-Oct-97	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-5.85	-47.3
R3	Nam Mae How	27-Oct-97	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-5.19	-44.1
R4	Nam Mae Pai	28-Oct-97	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-5.39	-46.1
R5	Nam Mae Tui	28-Oct-97	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-5.42	-45.1
R6	Nam Mae Tui	28-Oct-97	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-5.46	-45.8
R7	Wang River	28-Oct-97	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-5.93	-44.6
R8	Nam Mae Sai	28-Oct-97	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-6.29	-47.9
R9	Nam Mae Pang	28-Oct-97	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-5.12	-44.1
R10	Wang River	28-Oct-97	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-5.89	-46
R11	Wang River	15-Feb-02	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-5.85	-41.4
R12	Wang River	15-Apr-02	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-5.86	-42.4
R13	Wang River	15-Jun-02	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-6.47	-45.6
R14	Wang River	15-Aug-02	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-6.04	-44.4
R15	Wang River	15-Oct-02	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-6.11	-47.5
R16	Wang River	15-Dec-02	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-5.78	-42.7
R17	Kui Lom Dam	15-Aug-02	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-4.41	-36.8
R18	Kui Lom Dam	15-Apr-02	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-2.94	-26.5

N.A = No data

The hydrochemical data of the groundwater were provided by the Department of Groundwater Resources and the Royal Irrigation Department, Thailand. Hydrochemical data can be classified on the basis of the dominant ions by means of the Piper–trilinear diagram as hydrochemical facies.

The hydrogen and oxygen isotopic compositions of the water samples collected in 1997 were determined at the Research Institute of Materials and Resources, Akita University, Japan. The water samples collected in 2002 were analyzed at the Adelaide Laboratory, Australia. The variations in D/H and $^{18}O/^{16}O$ isotopic ratios in these water samples are expressed as per mil deviation (‰) with respect to standard mean ocean water (SMOW).[14] Isotopic ratios for hydrogen and oxygen isotopes are expressed as:

$$\delta ‰ = \frac{Rsample - RSMOW}{RSMOW} \times 1,000 \quad (1)$$

where R is the isotopic ratio of D/H or $^{18}O/^{16}O$

Results and Discussion

Hydrochemical Characteristics

In general, the physical and chemical properties of the groundwater, e.g., TDS, Ca, Mg, Na, K, Mn, Cl, SO_4, CO_3, HCO_3, NO_3, and F, are below the maximum levels prescribed for potable waters by the World Health Organization.[15] In some areas, however, the groundwater has high concentration of iron and manganese.

The classification for this study was determined using the Chemical Application, Groundwater for Windows, United Nations.[16] Hydrochemical data can be classified on the basis of the dominant ions by means of the Piper–trilinear diagram. The software will not calculate or display the classification if there is an imbalance in the chemical data between sums of the cations and the anions. For the purpose of this study, the maximum permissible "imbalance" was set at 10%. The basic conclusions derived from use of the Piper diagram are the hydrochemical facies of the waters[17] and enable distinctions to be made between bodies of groundwater in an aquifer that differ in their chemical composition. The facies is a function of the lithology, solution kinetics, and flow pattern of the aquifer.[3]

All of groundwaters from the three different aquifer units are similar in their hydrochemical facies. Sodium, calcium, bicarbonate, chloride, and sulphate are dominant, and have concentration ranges of 1 to 190, 3 to 81, 49 to 479, 1 to 51, and 1 to 245 mg/l, respectively. The main types of facies are Na^+-Ca^{2+}-HCO_3^-, Ca^{2+}-Na^+-HCO_3^-, Na^+-Ca^{2+}-HCO_3^--Cl^-+SO_4^{2-}, and Ca^{2+}-Na^+-HCO_3^--Cl^-+SO_4^{2-}. These are shown in Fig 4. The groundwaters from three different aquifer units do not differ in either chemical composition or hydrochemical facies, which indicates that all of the groundwaters in the three aquifer units is recharged by chemically similar water. The spatial difference in chemical constitution may arise as the water infiltrates through the soil into aquifer. The sodium in groundwater may derive from igneous and sedimentary rocks containing feldspar and clay, while calcium may come from carbonate rock in adjacent areas. Bicarbonate may come either from the carbonate rocks or from carbon dioxide in the atmosphere.

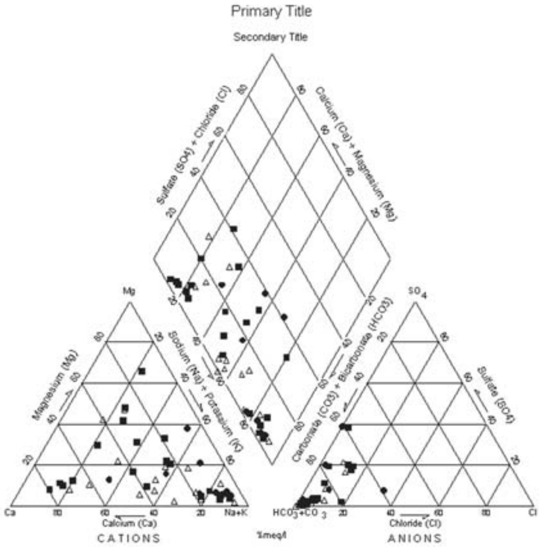

Fig 4. Hydrochemical facies of groundwater from three aquifer units. Square, triangle, and dot symbols represent groundwater samples from Qa, Qt, and T aquifer units, respectively.

Oxygen and Deuterium Isotopes

Interpretation of isotopic composition of the Lampang basin precipitation is facilitated by a discussion of the precipitation in Thailand. These data are available on the Internet in the framework of the Global Network of Isotopes for Precipitation, GNIP.[18] The δ-values for precipitation in Thailand are available for the period from January 1968 to December 2000. The δD and $\delta^{18}O$ values are given in the form of mean monthly values. The data indicate that monthly precipitation varied between 1 and 676 mm/month and the amount of rainfall is usually high during wet season (May to October). In this study data from the global network for isotopes in precipitation from the Bangkok station were used to derive δD-δ^{18}O relationships and to understand the isotopic characteristics of Thailand's precipitation. On this basis, Thailand's meteoric water baseline was defined as:

$$\delta D = 7.35\,\delta^{18}O + 6.11, \text{ with } R^2 = 0.972 \qquad \text{(Fig 5).}$$

The meteoric water baseline for Thailand is offset from the global meteoric water line of Craig.[19] This probably reflects the differential evaporation of water as its fall through the atmosphere. The lower slope of the curve for Thailand indicates evaporation under conditions of lower relative humidity.

The variations in isotopic composition of rainwater in Thailand shows clearly the variation between wet and dry season precipitation (Fig 5 and 6). The isotopic composition of rainwater in the dry season is enriched in heavy isotopes in comparision to that of the wet season, because of the effects of both the season and the rate of precipitation. In order to obtain a better understanding of the isotopic characteristics of precipitation in the Lampang area, ten rainwater samples were collected at different times, three during September and October, 1997, and seven during January and December, 2002. These samples show significant differences in δD-δ^{18}O values, their δD values being –85.5 to –33.6 ‰ and their δ^{18}O values being –11.42 to –5.80 ‰. The scatter in isotopic composition may be caused by restricted periods of high intensity rainfall, the effect of the precipitation, and the mixing regime between upper air and the vapor in the top of a large cloud system, which is very depleted in heavy isotopes. Fig 5 is a diagramatic plot of δD- δ^{18}O for precipitation in Thailand and in Lampang.

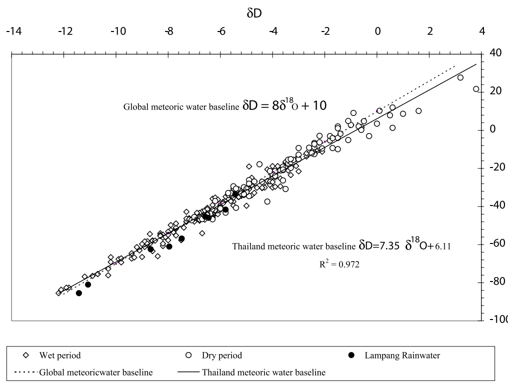

Fig 5. Plot of δD-δ^{18}O for Thailand meteoric water baseline and Global meteoric water baseline.

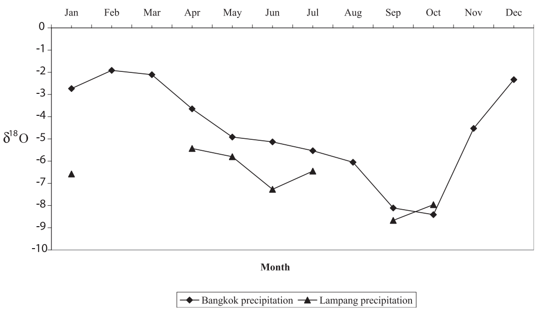

Fig 6. Show the variation of δ^{18}O between the wet season and dry season of Thailand and Lampang precipitation.

The trend and distribution of the δD-δ^{18}O data points for the Lampang rain water samples are not significantly different from the Thailand meteoric water line or the plot of the range of values of isotopic composition in the wet season. This suggests that the meteoric waters in the Lampang basin and in Thailand generally have the same vapor source. As a result, it was not thought necessary to define a meteoric water baseline for the Lampang basin. The baseline for meteoric water in Thailand was used instead.

The isotopic composition of all 48 groundwater samples from the three different aquifer units was also determined. These samples were collected during September and October, 1997, and during April and May, 2002. Twenty samples came from the Quaternary (Qa) aquifer, 19 from the Quaternary (Qt) aquifer, and nine from the Tertiary (T) aquifer (Table 2). The isotopic compositions of the ground- and surface-waters in the Lampang basin are plotted on the δD-δ^{18}O diagram (Fig 7). The isotopic composition of groundwater is close to that of the precipitation in the wet season. This similarity between the isotopic compositions indicates that groundwater recharge arises from local precipitation and infiltration. The isotopic composition of groundwater also shows that the main period of infiltration is during wet season (May-October). This is supported by the relationship between the rainfall data and the piezometric level of the groundwater in the monitoring well (Fig 8).

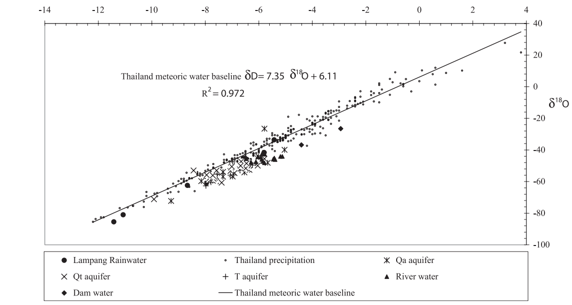

Fig 7. Plot of δD-δ^{18}O of groundwater from three different aquifer unit and surface water.

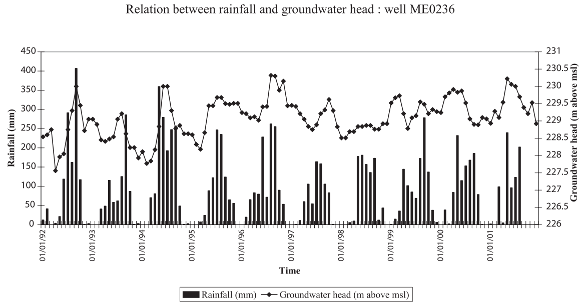

Fig 8. Hydrograph of monitoring well with rainfall record in the Lampang basin.

The trend and distribution of groundwater δD-δ^{18}O deviates significantly from the "local" meteoric water baseline (Thailand meteoric water baseline). This may reflect the evaporation of recharging water as it moves through the unsaturated zone. It is due to differential sorption and evapotranspiration by and from plants growing in the recharge zone. The groundwaters from the three aquifers studied are not significantly different in isotopic composition. The δD values of the Qa aquifer are –72.3 to –39.9 ‰, and its δ^{18}O values are –9.29 to -5.04 ‰. The Qt aquifer has δD values of –71.2 to –47.3 ‰ and d^{18}O values of –9.92 to -6.66 ‰. The T aquifer δD values are –62.7 to –48.3 ‰ and its δ^{18}O values are –7.98 to -6.66 ‰. The isotopic similarity between the different aquifer units indicates that the whole groundwater system is recharged by isotopically similar waters from local precipitation, that infiltration water is not fractionated within the aquifers, and that there is little or no interaction with minerals, even in the deeper water of the Tertiary aquifer (Fig 9).

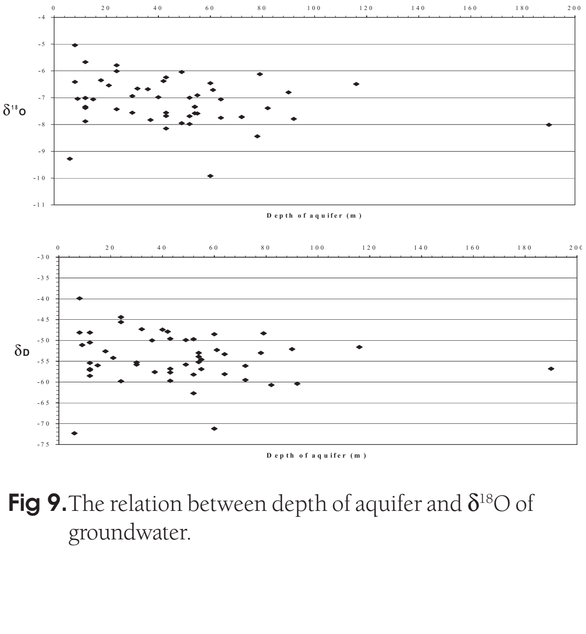

Fig 9. The relation between depth of aquifer and δ^{18}O of groundwater.

Surface water samples including water from both dams and rivers, often show evidence of hydrologic connection with the local groundwater system. Fingerprinting can be used as an additional tool to identify hydrologic interaction between these surface waters and the groundwater system. The two water samples from Kui Lom Dam were collected in April (dry season) and August (wet season), and ten river water samples during September and October 1997. A further six samples were collected from the river between January and December, 2002. These sample sets are representative of the months through the year and can be shown in the form of a flow hydrograph (Fig 10). As can be seen, the isotopic composition of the river water shows a small seasonal variation. The δD values of river water range from –48.1 to -36.8 ‰ while its δ^{18}O values range from –5.79 to -4.41 ‰. The δD and δ^{18}O values of surface water collected from a dam that feeds the Wang River are –36.8 to –26.5 ‰ and –4.41 to –2.94 ‰, respectively.

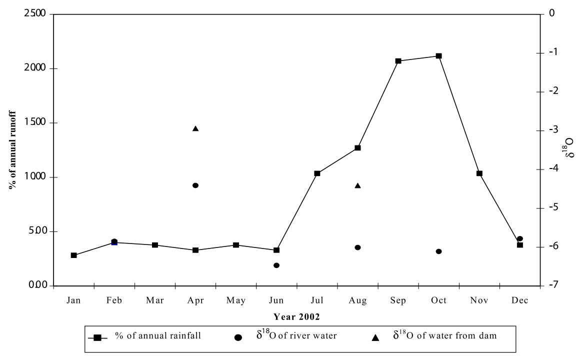

Fig 10. The variation in isotopic composition of the river water and water samples from Kui Lom dam in the Lampang basin.

The isotopic composition of the river and dam waters is enriched in heavy isotopes in comparison to that of the groundwater. The two Kui Lom dam samples were collected during the wet and dry seasons. The water from the dam flows into the river. The two samples from the dam contain higher proportions of heavy isotopes than the river water samples that were collected at the same time. This suggests that the isotopic composition of surface water samples from the dam changed as a result of evaporation in the pervasive subtropical climate of Thailand. The annual precipitation recorded at the local meteorological station in 2000 was 1,053 mm/year. The evapotranspiration rate was also very high, at 1,550 mm for the year. It is obvious that the dam is in an area of high evaporation.

The relatively low proportion of heavy isotope in the river water as compared to the water from the Kui Lom dam suggests that the water in the Wang river may be derived, at least partially, from the aquifers. The local groundwaters contain lower proportions of heavy isotopes than the river water. It is believed that these groundwaters are discharged by seepage from the coarse, unconsolidated, sediments of the alluvial aquifer (along the river bank). Seepage of groundwater into a stream occurs when the water table adjacent to the stream is higher than the water level in the river. This is supported by the relationship between the water table in the monitoring well ME0236, which is above the level in the river (the well is about 400 meters from the river) (Fig 11) and by the direction of groundwater flow to the river.

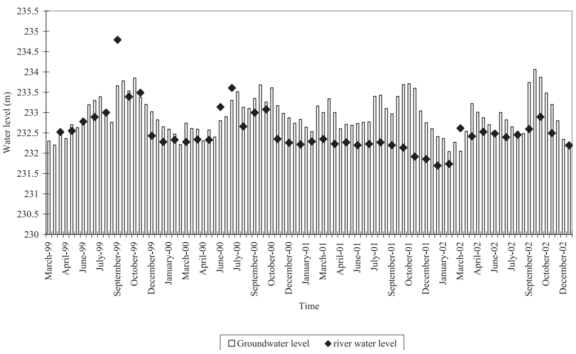

Fig 11. The relation between river water level and groundwater level.

CONCLUSIONS

In this study we have reported the hydrochemistry and the stable isotope (δD and $\delta^{18}O$) content of precipitation, surface water, and groundwater. We have used these to characterize the groundwater system in the Lampang basin. The hydrochemical facies of groundwater from the three main aquifer units are similar. The dominant cations and anions are sodium, calcium, bicarbonate, chloride, and sulphate. The main facies types are Na^+-Ca^{2+}- HCO_3^-, Ca^{2+}-Na^+-HCO_3^-, Na^+-Ca^{2+}-HCO_3^--Cl^-+SO_4^{2-}, and Ca^{2+}-Na^+- HCO_3^--Cl^-+SO_4^{2-}. Groundwater from the three different aquifer units does not differ in either chemical composition and hydrochemical facies, indicating that all of the groundwater from these units is likely to be recharged by same source.

The stable isotope composition of precipitation in the Lampang basin is not significantly different from the isotopic composition of precipitation elsewhere in Thailand. The Thailand meteoric water baseline is defined as $\delta D = 7.35\,\delta^{18}O + 6.11$, $R^2 = 0.972$, and this has been used as the reference line for local meteoric water.

Groundwater in the Lampang basin occurs in three main aquifer units. These are the Holocene and Pleistocene unconsolidated sediments, and the Tertiary unconsolidated and semi-consolidated sediments. The isotopic compositions of the groundwater in these three aquifers do not differ significantly from each other or that of local precipitation. This indicates that the groundwater in the Lampang basin is recharged by local precipitation during the wet season (May-October), that the infiltrating water does not fractionate within aquifers, and that there is little or no effect from water-rock interaction, even in the deeper water of Tertiary aquifer unit.

The isotopic composition of river water contains higher levels of heavy isotopes relative to that of the local groundwater, but lower than that of water from dam. The two possible explanation for this are that groundwater may be discharged by seepage from alluvial aquifers (river bank) into river, where they mix with water from the Kui Lom dam, or that there is a significant return flow of irrigation water to the river.

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