Subsurface Thermal Regime in the Chao-Phraya Plain, Thailand

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Abstract: Worldwide use of geothermal heat-pump (GHP) has extensively grown in recent two decades. Although generally geothermal heat-pump system may not have thermal merit for space cooling in tropics, there may be some places in tropical regions where subsurface can be used as “cold heat-source”. In order to confirm this possibility, subsurface temperature surveys were widely conducted in the Chao-Phraya plain, Thailand.

As a result, the distribution of subsurface thermal gradients has marked differences between the lower and the upper plain. Thermal gradients in the upper plain are low, and most of them are below 1.0 °C/100 m. The thermal gradients in the lower plain, on the other hand, are generally high and show a tendency of lower gradient at peripheral areas and higher gradient at central parts (4.0 °C/100 m). This subsurface thermal regime is due to thermal conduction by regional groundwater flow system in the lower plain estimated by chemical compositions and stable isotope variations.

Keywords: Chao-Phraya Plain, groundwater flow system, thermal advection, geothermal heat pump

1. Introduction

Geothermal heat-pump can be applied for both/ either space heating and/or cooling depending on surface and underground temperature conditions. Although space cooling is needed tropical countries where the atmospheric temperature is almost stable through a year, subsurface temperature may always be higher than atmospheric one because of geothermal gradient, and there is no thermal merit of geothermal heat-pump system. However, still there is a possibility of thermal merit for tropical regions if 1) seasonal change of atmospheric temperature exist, 2) daily change of atmospheric temperature is rather high, and/or 3) the cooling effect of recharging groundwater flow on subsurface temperature is locally dominant than the heating effect of heat flux from a depth. Thus to understand local underground temperature distribution may be the first step for an intensive installation of geothermal heat-pump system. For this purpose, vertical temperature profiling of observation wells were widely measured in Chao-Phraya Plain, Thailand.

It is known that subsurface temperature distribution is generally affected not only by thermal conduction but also by advection owing to groundwater flow (Uchida et al., 2003). The effect of thermal advection is especially large in shallow sedimentary layer with high

groundwater flux.

Groundwater temperature measured in an observation well is assumed to be identical to subsurface temperature, because there exists thermal equilibrium between the water in a borehole and its surrounding subsurface layers. Temperature profiles are one-dimensional sequential data arrays so that areally distributed temperature profiles provide three-dimensional subsurface information. Fig.1 shows groundwater flow system and subsurface thermal regime (modified from Domenico and Palciauskas, 1973). If there is no groundwater flow or static groundwater condition (Fig. 1a), subsurface thermal regime is governed only by thermal conduction and subsurface temperature gradient is constant (Fig. 1b). When a simple regional groundwater flow system due to topographic driving (Fig. 1c) is assumed, thermal regime will be disturbed by thermal advection owing to groundwater flow (Fig. 1d). In the groundwater recharge area, subsurface temperatures and gradients are lower than that of under static groundwater condition (Fig. 1b). In the discharge area, on the other hand, temperatures and gradients are larger than that of under static condition.

Uchida et al. (2003) compiled shallow subsurface temperature-depth profiles at depths from 30 m to 300 m in selected Japanese basins and plains. They classified thermal data sets into four categories depending on

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Fig. 1 Subsurface thermal regime affected by a groundwater flow system. (modified Domenico and Palciauskas, 1973)

- (a) static groundwater
- (b) thermal regime under condition of (a)
- (c) simple regional groundwater flow system
- (d) thermal regime under condition of (c)

the thermal regime and pointed out that main factor of subsurface temperature distribution is the effect of thermal transport due to regional groundwater flow system.

Uchida et al. (2005) obtained 16 temperature-depth profiles and other hydrological data by field measurement in the Sendai Plain, Northeast Japan to understand hydrogeological regime and subsurface thermal effects. Moreover, 3-D groundwater flow and heat transport model of the Sendai Plain showed that the change of thermal gradient near the basement of the Quaternary system can be explained by a hydrological effect. Tenma et al. (2007) simulated performances of hypothetical Groundwater Heat Pump systems in five different locations in the Sendai Plains based on a numerical model for the subsurface conditions reconstructed by Uchida et al. (2005). They showed that thermal energy can be stored more efficiently in the Tertiary system as compared to the Quaternary system in the Sendai Plain. Thus it is important to understand hydrodynamics condition of the place where a geothermal heat pump system will be installed.

2. Description of the study area

The Chao Phraya Plain, Thailand, consists of the upper and the lower plains divided at Nakhon Sawan Province (Fig. 2). The Bangkok Metropolitan, situated in the lower plain, has land subsidence and sea water intrusion due to excessive extraction of groundwater by pumping. The lower plain extends about 200 km from the north to the south and about 175 km from the west to the east. It is bounded on the west by the mountain ranges about 100 km from the Chao Phraya River, on the east by mountainous terrains about 75 km from the river, on the south by the Gulf of Thailand and on the north by series of small hills which divide it from the Upper Plain. The mean annual precipitation is 1190 mm in the lower plain. The geological formations in and around Bangkok Metropolitan are the basement complex and alluvial deposits constituting of aquifers in this area. Fig. 3 shows the hydrogeological conditions of the lower plain. The main aquifers in this area are unconsolidated deposits and subdivided into 8 aquifers. Total thickness of the aquifers is about 600m.

Fig. 3 Geological schematic around Bangkok city (a) and hydrogeology from Ayutaya to Gulf of Thailand (b), respectively (Bua-peng, 1990).

The upper plain extends about 250 km from the north to the south and about 140 km from the west to the east. The main rivers in the upper plain are Ping, Wang, Yom and Nan which flow from north to south and come into concurrence at Nakon Sawan Province. The mean annual precipitation in this area is 1202 mm. The alluvial sediments have been accumulated in the plain under the fluvial environment since Tertiary, forming the total thickness of about 250 m. These sediments are classified into three aquifers (Buapeng, 1990).

3. Results

The authors measured borehole temperature using a digital thermistor thermometer in 2 m intervals with a precision of 0.01 °C to obtain temperature-depth profiles of 56 observation wells from 2003 to 2005.

Fig. 4 shows distribution of subsurface thermal gradients in the Chao Phraya Plain based on observed temperature-depth profiles. The distribution of subsurface thermal gradients indicates differences between the upper and the lower plains. Thermal gradients in the upper plain are generally low and most of them are lower than 1.0 °C/100 m. Some of them show negative gradients. Some observation points show thermal gradients of 1.4 ~ 2.1 °C/100m regionally, because there exists a hot spring in the vicinity, the temperature of which is 60 °C or higher. The thermal gradients in the lower plain, on the other hand, are generally high and show a clear tendency that thermal gradient is higher in the central area and lower in the peripheral areas.

Water samples were collected at 54 points from 2003 to 2005 for chemical and stable isotope analysis (δD and $\delta^{18}O$) to estimate regional groundwater flow system in the Chao Phraya Plain. Fig. 5 shows chemical compositions plotted on Piper trilinear diagram. Fig. 6 shows areal distribution of chemical compositions indicated by typical stiff diagram. As a result, most of the samples belong to $Ca-HCO_3$ or $Na-HCO_3$ type. Some samples taken from peripheral of the plain belong to $Ca-HCO_3$ type. Samples from the places near the coastal regions at lower plain indicate influences of sea-water intrusion in their chemical compositions. Large groundwater withdrawals during recent years around Bangkok City have resulted in large potentiometric-level declines. These declines, in turn, have caused problems with land subsidence and salt-water intrusion (Ramnarong and Buapeng, 1991).

Fig. 7 shows delta diagram of δD and $\delta^{18}O$. A relation between δD and $\delta^{18}O$ in the Chao Phraya Plain can be expressed as follows:

$$\delta D = 5.2\delta^{18}O - 10.8$$

Since stable isotope ratios of groundwater and spring water appear along a common line with those of river

water, the origin of groundwater and spring water may be regarded as meteoric water. Variations of δD and $\delta^{18}O$ are classified into two groups according to the area. Ranges of δD and $\delta^{18}O$ variations of the upper plain are wide as follows:

$$\delta D: -45.0 \sim -60.0, \delta^{18}O: -6.3 \sim -8.4$$

Ranges of δD and $\delta^{18}O$ variations of the lower plain except of GWA100, on the other hand, are narrow as follows:

$$\delta D: -45.0 \sim -55.0, \delta^{18}O: -6.3 \sim -7.5$$

The samples of the lower plain, moreover, show higher isotopic ratios than those of the upper plain.

GWA76 and GWA78, are in a same location but their sampling elevations are -141m and -51m, respectively, and the isotopic ratio of GWA76 is significantly lower than that of GWA78. Similarly the isotopic ratio of GWA50 (sampling elevation: -89m) is lower than that of GWA52 (sampling elevation: 13m). The isotopic ratio of GWA100, which elevation is -195m, shows the lowest value in the Chao Phraya Plain.

4. Discussion

Groundwater generally changes its chemical compositions from $Ca-HCO_3$ to $Na-HCO_3$ type by ion-exchange while flowing underground. The chemical compositions in the Chao Phraya Plain show that peripherals of the plain belong to $Ca-HCO_3$ type and central part of the lower plain belongs to $Na-HCO_3$ type. Moreover, a map of stiff diagrams in the lower plain shows that ion concentrations of central part are higher than those of peripheral area. These results suggest that the residence time of groundwater in the central part at the lower plain is longer than that in the peripheral area. Sanford and Buapeng (1996) constructed numerical model of the Bangkok Plain (lower Chao-Phraya Plain) and showed simulated groundwater age that groundwater age in the central part is older than that in the peripheral area. This simulation model has advocated our hypothesis of groundwater residence time. Map of stiff diagrams in the upper plain, on the other hand, shows same chemical composition in the peripheral and central area. It suggests that residence times of groundwater at sampling point are not so different.

The isotopic ratio of groundwater at a depth is lower than that at shallow part for an identical location (GWA 76 and 78, GWA 50 and 52 in Fig. 7). These results suggest that isotopic variations occurred due to difference of groundwater flow system. Moreover, the isotopic ratio taken from a depth of 195 m near Ayuthaya city shows lowest value in the plain. Therefore, that groundwater flow system at a depth of 200 m or deeper

Fig. 4 Distribution of subsurface thermal gradients and typical temperature-depth profiles.

○ : Lower Plain ● : Upper Plain

Fig. 5 Chemical compositions of the samples plotted on Piper trilinear diagram.

may differ from one at a depth of 150 m or shallower.

Considering that the aquifer thickness of the lower plain is thicker than that of the upper plain, scales of the groundwater flow system must differ in the upper and the lower plains. Analysis results of chemical compositions and stable isotope variations suggest that groundwater circulation occurs also in a depth in the lower plain.

The spatial variation of subsurface thermal gradient is different in the upper and the lower plains. Thermal gradient in the lower plain is higher in the central part and lower in the peripheral areas. This subsurface

thermal regime is due to thermal conduction by regional groundwater flow system in the lower plain. Thermal gradients in the upper plain, on the other hand, are generally low and most of them are 1.0 °C/100 m or lower, because of the small and shallow groundwater flow system in this area.

5. Conclusions

GHP system needs heat exchange tube with 50-100 m depth, therefore, temperature-depth profiles are useful for set out of GHP system. The authors conducted

Fig. 6 Distribution of chemical components indicated by typical stiff diagram. Diagram of gray colored shows twofold concentration as legend.

Fig. 7 Delta diagram

borehole temperature measurement to obtain groundwater temperature-depth profiles at 58 observation points. The purpose of this study is to understand local subsurface temperature distribution for future installations of geothermal heat-pump systems in Chao-Phraya Plain, Thailand. As a result, the spatial variation of subsurface thermal gradients in the upper and the lower plains shows differences. Thermal gradients in the upper plain are low and most of them are below 1.0 °C/100 m. On the other hands in the lower plain, thermal gradient is low in the peripheral areas and high in the central part. It is suggested that this variation of thermal gradient in the lower plain due to thermal advection by regional groundwater flow system circulating in a deeper part. Data sets of chemical compositions and stable isotope variations support to understand background of subsurface thermal regime.

As for possibility of GHP application in the Chao-Phraya Plain, observation results suggest that subsurface thermal condition in the upper plain may be suitable for cold heat-source of GHP systems.

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Table 1 List of observation wells for subsurface temperature measurement.

No.	Site name	Latitude	Longitude
1	NB7	13°55'45"N	100°44'47"E
2	NB84	13°45'02"N	100°53'17"E
3	NB8	13°44'25"N	100°39'47"E
4	NB28	13°46'03"N	100°39'01"E
5	NB29	13°36'07"N	100°42'14"E
6	NB77	13°30'48"N	100°45'27"E
7	DMW4	13°35'30"N	100°21'59"E
8	NB69	14°11'25"N	100°31'37"E
9	AY1503	14°21'45"N	100°32'18"E
10	DR123	14°34'44"N	100°28'58"E
11	MQ1027	14°31'05"N	100°12'39"E
12	NB90	14°49'08"N	100°05'32"E
13	NB65	13°53'08"N	100°18'48"E
14	B-1	14°04'42"N	100°36'42"E
15	GWA0100	14°28'14"N	100°06'43"E
16	GWA0081	14°11'46"N	100°07'35"E
17	GWA0076	14°22'58"N	100°51'42"E
18	GWA0050	14°51'50"N	100°33'18"E
19	GWA0043	15°01'04"N	100°06'22"E
20	GWA0041	15°01'04"N	100°06'22"E
21	DI421	16°28'15"N	99°52'17"E
22	ARD0001	16°57'14"N	99°57'23"E
23	DC640	17°23'30"N	99°59'00"E
24	MB1000	17°55'59"N	99°55'59"E
25	MM0233	16°50'06"N	99°47'51"E
26	DI219	16°22'50"N	99°30'44"E
27	GWA0026	15°21'33"N	100°03'29"E
28	GWA0024	15°28'30"N	100°05'19"E
29	MC1161	15°46'19"N	100°05'35"E
30	PC25263	16°18'02"N	100°06'11"E
31	MD795	16°13'42"N	100°21'19"E
32	PC152	16°09'11"N	100°37'31"E
33	TA0037	16°16'42"N	100°24'26"E
34	1814	16°43'05"N	100°01'03"E
35	TTC6	16°50'08"N	100°22'13"E
36	PL25147	17°04'26"N	100°04'27"E
37	DC262	17°09'55"N	100°01'46"E
38	MB0945	16°58'20"N	99°50'09"E
39	DI0029	16°50'23"N	99°46'58"E
40	TV390CCS004	13°40'39"N	101°12'48"E
41	TE540CCS003	13°44'35"N	101°30'50"E
42	TE542CCS005	13°44'39"N	101°30'38"E
43	TBR578PB003	13°52'16"N	101°09'03"E
44	NB0089	13°52'58"N	100°11'38"E
45	NL0090	13°52'58"N	100°11'38"E
46	NB0088	13°57'34"N	100°03'50"E
47	NB0091	13°47'43"N	99°59'28"E
48	CWE80	13°45'46"N	99°46'37"E
49	CWE79	13°54'06"N	99°37'34"E
50	GWA0058	14°42'53"N	100°33'13"E
51	GWA0047	14°53'00"N	100°22'37"E
52	DR0119	15°00'51"N	100°15'47"E
53	GWA0036	15°08'45"N	100°14'50"E
54	GWA001	15°01'55"N	100°22'18"E
55	GWA003	14°58'41"N	100°22'53"E
56	Kampanphet office	16°32'08"N	99°28'07"E

タイ・チャオプラヤ平野の地下温度構造

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要 旨

この20年間で、地中熱ヒートポンプシステム（GHP）は世界的に広まっている。一般的に、地中熱ヒートポンプシステムは、熱帯地域において冷房に利用することは不利であると言われているが、場所によっては地下を冷熱源として使える場合も考えられる。本研究では、上記の可能性を評価するため、タイ・チャオプラヤ平野において地下温度構造の現地調査を実施した。

現地調査の結果、上部チャオプラヤ平野と下部チャオプラヤ平野とは、その地温勾配に大きな差異のあることが明らかとなった。上部チャオプラヤ平野の地温勾配は、全体的に $1.0^{\circ}\text{C}/100\text{m}$ 以下と小さいのに対し、下部チャオプラヤ平野では、平野の周辺では小さく、中央部で $4.0^{\circ}\text{C}/100\text{m}$ 以上と大きくなる傾向を示した。以上の結果は、チャオプラヤ平野において地中熱利用ヒートポンプシステムの導入を想定した場合、全体的に地温勾配の小さい上部平野の地下が冷熱源として利用できる可能性を示唆している。

Appendix fig. Temperature-depth profiles.

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