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Original Article

Groundwater temperature measurement of Chiang Mai basin

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Abstract

Groundwater temperature is one of the main factors that is considered when deciding on installation of a vapor compression refrigeration system with groundwater used for heat transfer. Groundwater temperature measurement is a necessity for the system installation. A total of 75 groundwater wells within the Chiang Mai Basin were selected for temperature monitoring stations. The temperature-depth profile of shallow groundwater showed that temperature had little change below 2 m depth from the water table. The temperature-depth profile of deep groundwater showed the separation of upper and lower temperature zones. Mostly, the temperature of the upper zone of deep groundwater has a positive slope. The temperature of the lower zone of deep groundwater is relatively constant. Both the shallow and deep groundwater temperatures are below the atmospheric temperature. The seasons, hydrogeologic units, and land use types have affected groundwater temperature of the Chiang Mai Basin only little.

Keywords: groundwater, temperature-depth, vapor compression refrigerant, Chiang Mai

1. Introduction

The heat pump system is a renewable energy technology for space cooling. The heat pump system uses a refrigerant to absorb and remove heat from the inside and transfer it to the outside (Omer, 2008). The common type of heat pump system for space cooling is the vapor compression refrigeration system (Stauffer, Bayer, Blum, Molina-Giraldo, & Kinzelbach, 2010). It is the most widely used method of air conditioning.

Groundwater is a low-temperature renewable energy resource. Worldwide, the use of groundwater as a resource for heating or cooling is increasing (Tissen, Benz, Menberg, Bayer, & Blum, 2019). Yasukawa, Uchida, Tenma, and Buapang (2004), Yasukawa *et al.* (2009) and Uchida *et al.* (2011) described that groundwater can be used by refrigeration systems in an area where the subsurface temperature is below the atmospheric temperature, in some seasons or during the day. It is then possible to remove heat from the system to the groundwater instead of to the outside air.

A schematic diagram of the vapor compression refrigeration system using groundwater as the heat sink is shown in Figure 1. The performance of a vapor compression refrigeration system with groundwater heat sink benefits from the difference between groundwater temperature and room temperature, which affects the work by compressor needed in the system and energy efficiency ratio (EER). If groundwater temperature and room temperature are almost equal, the air conditioning system will consume minimal electric power in a working system.

Therefore, groundwater temperature measurement is a necessity for vapor compression refrigeration system installation. One wants to find a groundwater depth at which its temperature become relatively stable (Wu, Xu, Zhou, & LaMoreaux, 2015). Wang *et al.* (2022) described that the performance of a vapor compression refrigeration system is highly dependent on the groundwater temperature, the amount

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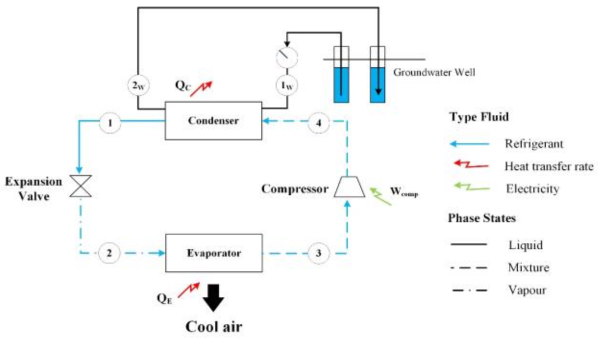

Figure 1. A schematic diagram of the vapor compression refrigeration system with groundwater used for heat sink

of water, and the volume of exhaust air. Therefore, groundwater temperature measurement is a necessity for vapor compression refrigeration system installation.

Chiang Mai Basin is a rapidly developing area and is the economic center of northern Thailand. The increase in energy demand affects living costs. The vapor compression refrigeration system is considered for reducing energy consumption. The purpose of this study was to determine groundwater temperatures in Chiang Mai Basin for designing a vapor compression refrigeration system.

1.1 Study area

Chiang Mai Basin is located in the northern part of Thailand. It is kidney-shaped with the main axis oriented in the northeast-southwest direction. The basin is accompanied by mountain ranges. The topography of the Chiang Mai Basin is classified into 3 major parts including a high mountainous area, a hilly and rolling area, and a plain area in the middle. The study area is located within the plain area covering about 2,841.45 km^2 (Figure 2). Winter, summer, and rainy season are the three seasons in the area. Average meteorological data in a thirty-year period (1981–2010) were provided by the Northern Meteorological Center (2016). The mean annual rainfall was 1,140.2 mm.

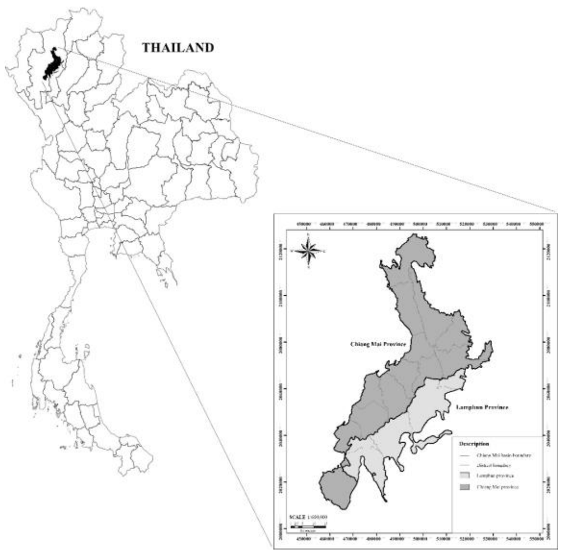

Figure 2. Chiang Mai Basin

1.2 Hydrogeologic setting

Hydrogeology of Chiang Mai Basin consists of Tertiary to Quaternary deposits and it is apparent that consolidated rocks and unconsolidated rocks are the main aquifer of the area as shown in Figure 3. The consolidated rocks were forming a mountain area in the western part and are divided into 3 hydrogeological units, namely (1) Permian-Carboniferous limestone aquifer, (2) Permian – Carboniferous metasediment aquifer, and (3) Ordovician limestone aquifer. The unconsolidated rocks cover approximately 2,800 km^2 in the central and eastern parts of the area. They were divided into 3 hydrogeologic units, namely (1) Flood plain deposits aquifer, (2) Young terrace deposits aquifer, and (3) Old terrace deposits aquifer (Department of Groundwater Resources, 2008; Klaytae, 2005; Seanton, 2010; Tatong, 2000).

1.3 Land use types

Land use types of Chiang Mai Basin are described by the GIS Enterprise Access Database of Chiang Mai province and Lamphun province (2018). Land use types of the study area consist of building and village area, agricultural land, reservoir, industrial area, forest, wetland, park, bare land, and others.

2. Methodology

2.1 Groundwater temperature measurement

A total of 75 groundwater wells within the Chiang Mai Basin were selected as the temperature monitoring stations and two monitoring wells were equipped with automatic temperature loggers. The deep wells belong to the Department of Groundwater Resources. The well screen is an opening through which water enters the well casing from aquifer. Figure 3 illustrates groundwater well location and examples of hydrogeologic cross-sections in lines AA′. The cross-section is generated from several lithologic logs. Groundwater wells are selected based on the following criteria: they are spatially distributed throughout the basin, hydrogeological units and land use types. The temperature was measured by lowering down a thermocouple probe into the well. Precautions were taken to ensure that the recorded temperature was representative of water in the aquifer. The equipment can measure temperatures in the wells with accuracy of ± 1.1°C. The temperatures were measured at 1 m depth intervals and recorded when the measurement was stable. The automatic temperature loggers were set at depths of 4 m and 12 m below the ground surface for continuous temperature monitoring once every hour with an accuracy of ± 0.2°C.

The shallow observation wells have a depth of less than 20 m from the ground surface. Groundwater level varies depending on the season and the topography in the area. The deep observation wells have a depth of at least 20 m from the ground surface. Although shallow groundwater level fluctuates seasonally, it can be used for vapor compression refrigeration system if the temperature is suitable.

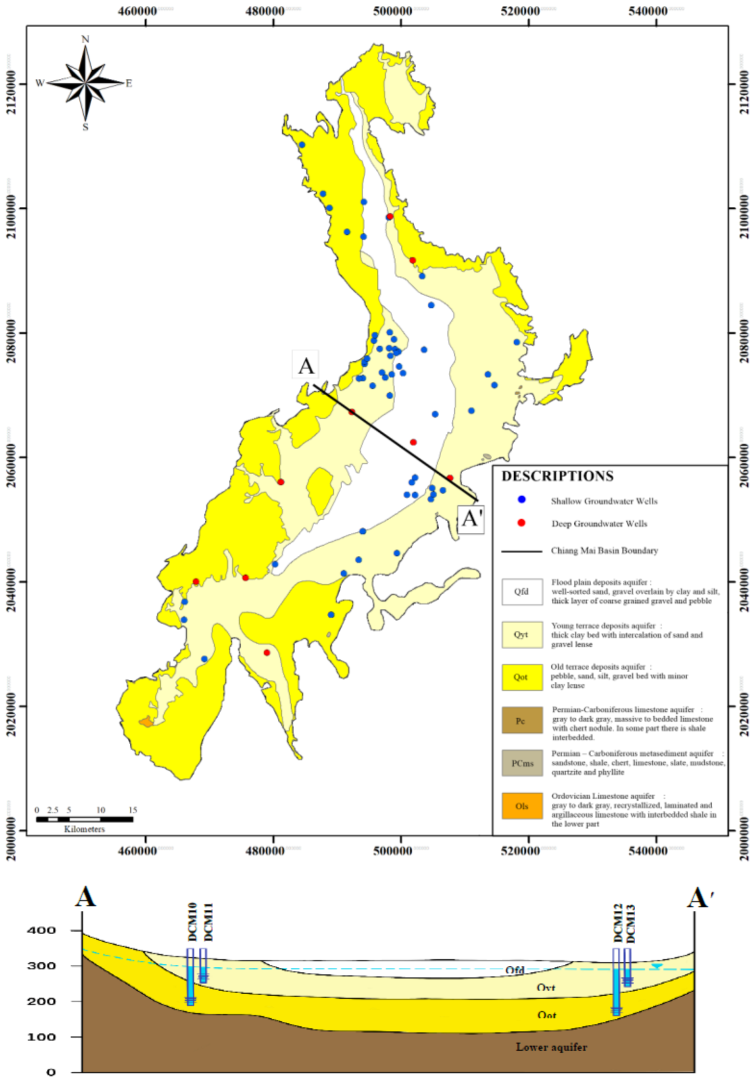

Figure 3. Hydrogeology of Chiang Mai Basin and cross-section AA′

2.2 The temperature gradient

The depth profiles of groundwater temperature in the wells can be used to determine the temperature gradient and the coefficient of determination (R-squared). Two types of the gradient are positive and negative. A negative gradient shows the temperature decreasing with depth and a positive gradient shows the temperature increasing with depth. A steeper slope represents stable groundwater, while if the temperature slope is approaching zero, the groundwater temperature will fluctuate. R-squared is a statistical measure indicating how strong is the correlation of groundwater temperature with depth.

2.3 The inverse distance weighted method (IDW)

The groundwater temperature gradient for each season was used with the inverse distance weighted method (IDW) to interpolate, because this method requires a small number of data points and gives a smooth result. This study used the relationship of slope and temperature change to classified temperature gradient ranges. If the slope changes by about 0.059, the temperature will be increased by 1°C. Table 1 shows temperature gradient range classification.

2.4 Statistical methods

The analysis of variance (ANOVA) is a statistical method that assesses potential differences in the dependent variable. If the F-value is higher than its critical value, this indicates a significant difference between groups. If the F-value is lower than the critical value, there is no significant difference between groups. ANOVA can indicate the relationship between groundwater temperature and parameters that influence temperature changes.

The study used a t-test in hypothesis testing to compare temperature slopes between groundwater wells, i.e. whether they differ with statistical significance.

Table 1. Temperature gradient ranges

Temperature gradient	Range
<0.059	High
0.06 - 0.147	Moderate
0.148 - 0.174	Fair
>0.174	Poor

3. Results and Discussion

3.1 Depth profiles of temperature

Temperature-depth profiles (T-D profiles) were observed for the observation wells during January – December 2018 once every month and automatic temperature loggers were recording temperature changes during each day. The results show groundwater temperatures having slight changes, being less than 1 °C at depth of 4 m and constant at depth of 12 m. The fairly constant temperature is advantageous for the vapor compression refrigeration system installation, because it allows good system performance. However, groundwater temperature should be lower than the atmospheric temperature.

The T-D profiles of shallow observation wells in the same hydrogeologic unit show different patterns in the same season. Likewise, T-D profiles of shallow observation wells in each season show different patterns (Figures 4 and 5). The T-D profiles of shallow groundwater wells in various land use types show only little difference in profile patterns in each season. The hydrogeologic unit could have more impact on T-D profiles than the land use type or the season.

The T-D profiles of the deep observation wells show temperature variations of approximately 1-3 °C (Figures 6 and 7). The hydrogeologic unit and season influence groundwater temperature-depth profiles more than land-use type.

The T-D profiles of shallow and deep groundwater wells indicate that the temperature at a depth below 2 m from the water table in the shallow groundwater wells and a depth below 15 m from the water table in the deep groundwater wells only experiences slight changes.

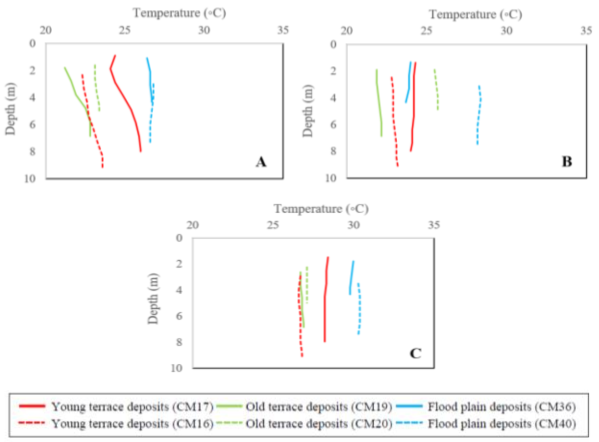

Figure 4. Temperature–depth profiles (T-D profiles) of shallow groundwater wells located in various hydrogeologic units A) T-D profiles measured in April during the summer B) T-D profiles measured in July during the rainy season. C) T-D profiles measured in November during the winter

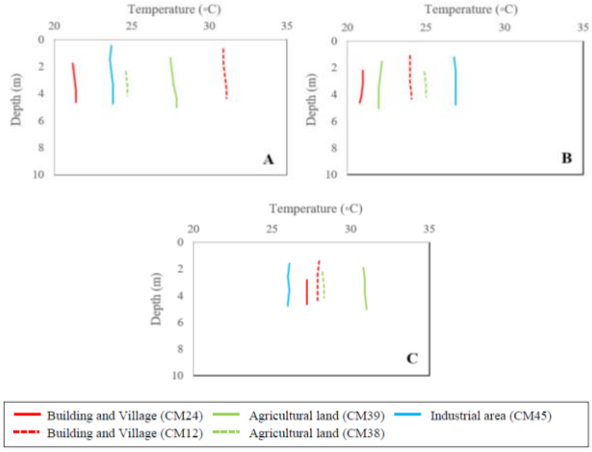

Figure 5. Temperature–depth profiles (T-D profiles) of shallow groundwater wells in various land-use types: A) T-D profiles measured in April during the summer, B) T-D profiles measured in July during the rainy season, and C) T-D profiles measured in November during the winter

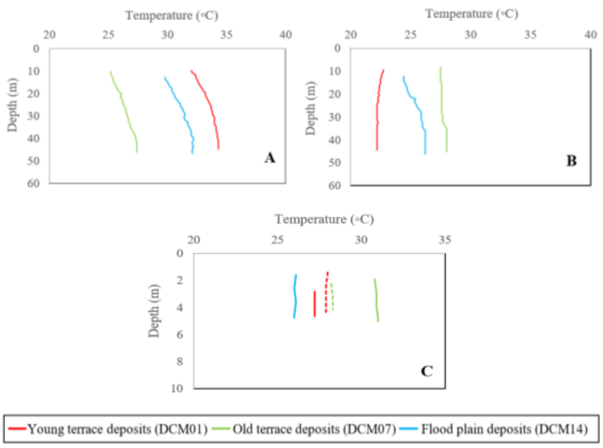

Figure 6. Temperature-depth profiles (T-D profiles) of deep groundwater wells in the various hydrogeologic units A) T-D profiles measured in April during the summer B) T-D profiles measured in July during the rainy season C) T-D profiles measured in November during the winter

3.2 Pattern of groundwater temperature variations and temperature gradient

The shallow groundwater temperature-depth profiles are classified into 2 types based on the slope being positive or negative. Mostly, shallow groundwater temperature has a positive slope and high slope values. A negative slope was found in the late rainy season to winter. The t-test for hypothesis testing indicated that the temperature gradient through the year 2018 of each well had no differences in their statistical means. The shallow groundwater temperature gradient maps are shown in Figure 8.

The deep groundwater temperature-depth profiles are classified by positive or negative gradient. The deep groundwater temperature changes in the upper and lower zones are distinguished. The slope shape was used to separate temperature-depth profiles into upper and lower deep

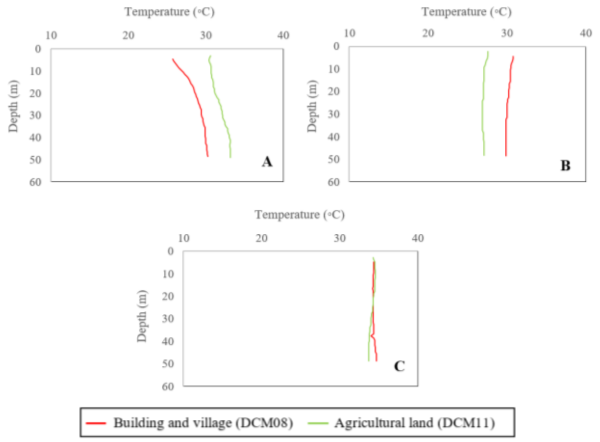

Figure 7. Temperature-depth profiles (T-D profiles) of deep groundwater well in the various land-use types: A) T-D profiles measured in April during the summer, B) T-D profiles measured in July during the rainy season, and C) T-D profiles measured in November during the winter

groundwater zones. Mostly, the upper deep groundwater temperature has a high positive slope. The lower deep groundwater temperature is relatively constant.

Nine of the 14 deep groundwater wells had the t-test for hypothesis testing fall in the acceptance zone, indicating that the differences of average deep groundwater temperature gradients among groundwater wells had no statistical significance. The deep groundwater temperature gradient maps are shown in Figure 9.

3.3 Groundwater temperature under different conditions

The groundwater temperature at a depth below 2 m from the water table mainly had only slight variations in temperature with depth. Figure 10 compares the atmospheric and shallow groundwater temperatures at different depths during January – December 2018. The average maximum atmospheric temperature, the average surface temperature, and the average groundwater temperature at each depth display mainly similar patterns. The average groundwater temperatures of January and February deviated from the pattern.

1) Seasons

The average shallow groundwater temperatures at each depth showed similar values. When considering the seasonal average of surface temperature, it was higher than the shallow groundwater temperature throughout this study.

2) Hydrogeological units

The average shallow groundwater temperature patterns for each hydrogeologic unit had slight differences. The wells in the flood plain deposits aquifer had a higher average groundwater temperature than the wells in the young terrace and old terrace deposits aquifers, with differences in temperature of less than 1.5 °C and less than 2.3 °C.

3) Land-use type

The average shallow groundwater temperature patterns in various land-use types did not differ considerably. The wells in the building and village area and in the agricultural land had very similar temperatures. Both had a higher average groundwater temperature than groundwater wells in the industrial area.

In the shallow groundwater, the F-test results for hypothesis testing can be interpreted so that the groundwater temperature through the year 2018 by well had no significant difference in mean values. The seasons, hydrogeologic units, and land-use types had little effect on the shallow groundwater temperature of the Chiang Mai Basin. Details of shallow groundwater temperature for each condition are listed in Table 2.

In this study, the deep groundwater temperature changes in the upper (above 15-20 m) and lower (below 20 m) zones were noticed. Mostly, the upper zone of deep groundwater temperature has a high positive slope. The lower zones of deep groundwater temperature were mainly of interest because they had only slight variations in temperature by depth.

Figure 11 compares atmospheric and deep groundwater temperatures at different depths during January – December 2018. The average maximum atmospheric temperature, the average surface temperature, and the average groundwater temperature at each depth display mainly similar patterns. The average groundwater temperatures of May and July deviated from the pattern.

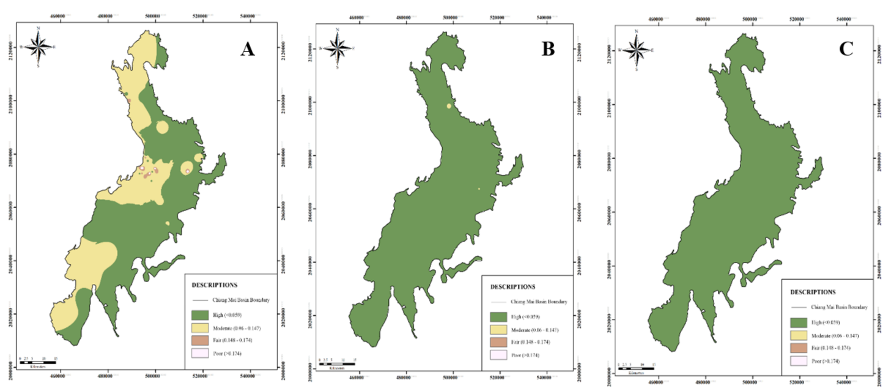

Figure 8. The shallow groundwater temperature gradient maps for A) summer, B) rainy, and C) winter season

A

B

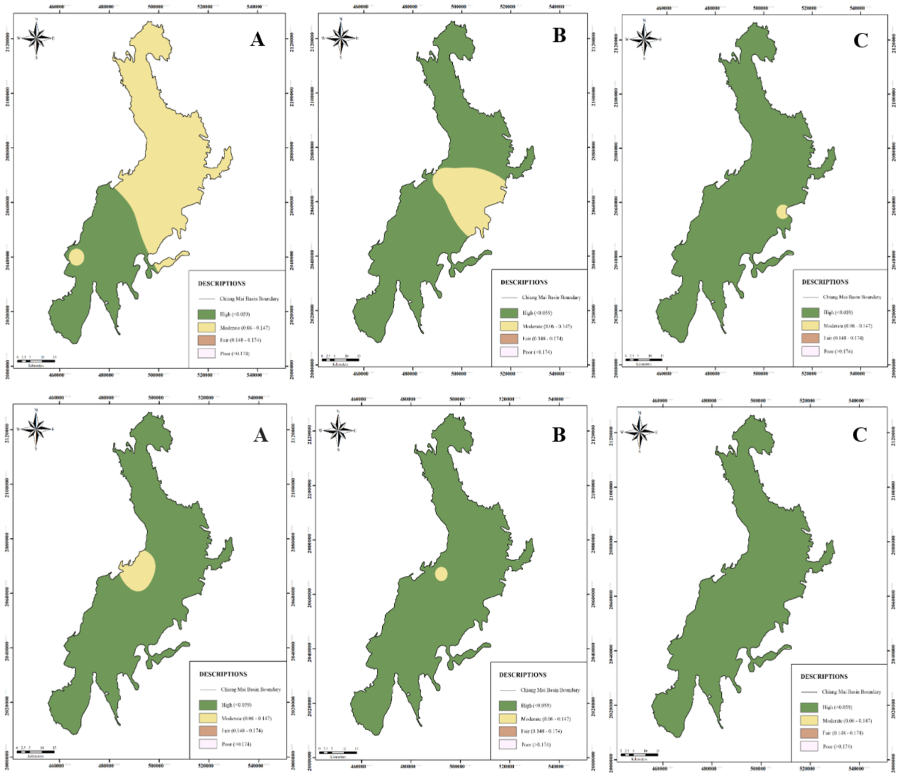

Figure 9. (A) The upper, (B) The lower deep groundwater temperature gradient maps for A) summer, B) rainy, and C) winter season

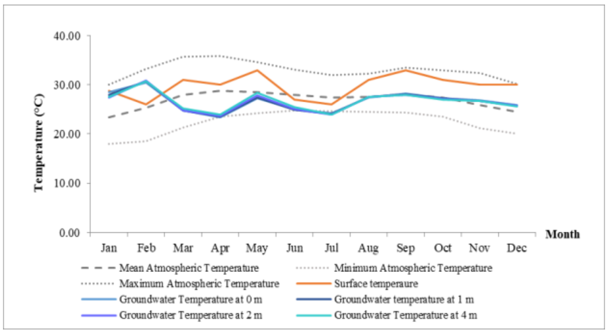

Figure 10. Comparison of time profiles of atmospheric and average shallow groundwater temperatures by depth below the water table

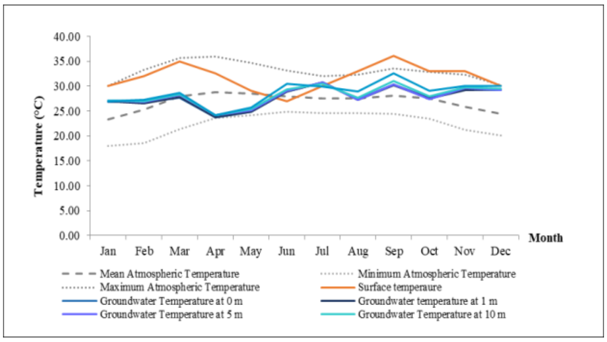

Figure 11. Comparison of time profiles of atmospheric and deep groundwater temperatures by depth below the water table

1) Seasons

The average deep groundwater temperature showed similar values at each depth and the temperature slowly increased with depth. There was a higher temperature in the summer than in the rainy season. In addition, the surface temperature was higher than the deep groundwater temperature.

2) Hydrogeological units

The average deep groundwater temperature patterns for each hydrogeologic unit had slight differences. The wells in the young terrace deposits aquifer had the highest average groundwater temperature. The groundwater temperature of the wells in the old terrace deposits aquifers was higher than in the well in the flood plain deposits aquifers. Each unit had a different average temperature by 1 - 2˚C.

3) Land-use types

The average deep groundwater temperature patterns by the various land-use types were not significantly different. The wells in the building and village area had a higher temperature than the wells in the agricultural land. The temperature increased with depth. Each unit had a different average temperature by 1˚C.

The F-test values for hypothesis testing indicated that the average deep groundwater temperature under each condition was not significantly different in the statistical mean. The seasons, hydrogeologic units, and land-use types

Table 2. Summary of shallow groundwater temperatures (˚C) in different conditions

Conditions			Depth below the water table (m)						Surface temperature
			0	1	2	3	4	5	
Season	Summer	Min	22.88	21.80	21.60	22.70	23.45	23.60	23.25
		Max	28.05	28.68	29.50	28.33	28.35	28.35	33.13
		Mean	25.35	25.35	25.21	25.37	25.48	25.60	28.88
	Rainy	Min	24.18	24.13	23.70	24.35	24.05	23.20	24.50
		Max	31.08	30.75	30.73	31.13	29.35	29.17	31.25
		Mean	27.49	26.85	26.79	26.94	26.59	26.62	28.23
	Winter	Min	24.15	24.23	25.67	25.67	25.73	25.87	22.83
		Max	30.42	31.00	32.20	30.97	31.30	30.90	31.33
		Mean	27.57	27.95	28.09	27.90	27.75	27.66	27.80
Hydrogeo-logical unit	Young terrace deposits	Min	24.53	24.53	24.60	24.66	24.12	24.83	24.32
		Max	29.01	30.90	28.86	28.85	27.90	27.88	30.86
		Mean	26.81	26.72	26.56	26.60	26.22	26.54	28.46
	Old terrace deposits	Min	24.37	24.05	24.30	24.62	24.73	24.05	26.36
		Max	27.38	27.01	27.02	27.01	27.00	28.50	28.32
		Mean	25.43	25.35	25.51	25.72	25.58	26.28	27.57
	Flood plain deposits	Min	25.92	25.94	26.11	26.30	26.66	27.09	24.86
		Max	29.55	29.35	29.30	30.40	28.80	28.00	31.64
		Mean	27.36	27.26	27.41	28.01	27.85	27.54	28.49
Land use type	Building and Village	Min	24.37	24.40	24.48	24.62	24.67	24.05	24.32
		Max	29.55	30.90	29.30	30.40	28.80	28.00	31.64
		Mean	26.75	26.68	26.58	26.74	26.45	26.43	28.39
	Agricultural Land	Min	24.39	24.05	24.30	25.54	24.80	27.88	26.83
		Max	27.94	27.90	28.18	28.50	27.90	28.50	30.77
		Mean	26.79	26.59	26.82	27.41	26.57	28.19	28.36
	Industrial area	Min	25.90	25.46	25.51	25.55	24.12	-	26.32
		Max	25.90	25.46	25.51	25.55	24.12	-	26.32
		Mean	25.90	25.46	25.51	25.55	24.12	-	26.32

(-) No more detail at depth of 5meters below ground surface.

had little effect on the deep groundwater temperature of the Chiang Mai Basin. Details of the deep groundwater temperature under each condition are listed in Table 3.

4. Discussion

The important step for installing a vapor compression refrigeration system is mapping local groundwater temperature and assessing the factor data that influence the groundwater temperature in the area. Groundwater temperature is the main factor in evaluating the feasibility of installing a vapor compression refrigeration system.

Taylor and Stefan (2009) described that the groundwater temperature in an urbanized downtown area was nearly 3 ˚C warmer than that in an undeveloped agricultural area. Öngen and Ergüler (2021) described that the urban centers have higher air temperature and groundwater temperature anomalies than surrounding rural area. In the study, groundwater temperature was measured in the wells when they are not in use. Temperature is constant, without flow into the wells. The shallow groundwater wells located in the building and village area and agricultural land had pretty similar temperature-depth profiles. Both of them had a higher temperature than wells located in the industrial area. The deep groundwater wells located in the building and village area had a higher temperature than the wells located in agricultural land, similar to groundwater temperature results of previous studies. The study can indicate that the land use type influences groundwater temperature.

The temperature-depth profile of shallow groundwater wells showed a relatively stable temperature below 2 m depth from the water table and a positive gradient. In the deep groundwater wells, the upper deep groundwater temperature zone had a positive high gradient. The lower deep groundwater temperature was relatively constant.

The groundwater temperature potentiality map helps when considering vapor compression refrigeration system installation. The common system uses refrigerant to absorb and removes heat from the inside and transfers it to the outside. When groundwater temperature and room temperature are nearly equal, the system will have low electricity use that can save energy and reduce operating costs. Therefore, the atmospheric temperature should have a maximum temperature higher than groundwater temperature. Assuming a room temperature of approximately 25˚C, the groundwater temperature below 25 °C shows a very high potential for heat sink use.

The shallow groundwater temperature was in the range of 24.05 – 30.90 ˚C and 26.01 – 32.14 ˚C for deep groundwater. The groundwater temperature was lower than the average atmospheric temperature in the study area. The water has a better ability for serving as heat sink than the ambient air. Groundwater can be applied for the vapor compression refrigeration system. Detailed investigations should be planned and performed. The evaluation of the interaction influence factors such as groundwater temperature, temperature gradient, depth of water table, recharge

Table 3. Summary of deep groundwater temperatures (˚C) in different conditions

Conditions			Depth below the water table (m)								Surface temperature
			0	1	2	5	10	15	20	30	
Season	Summer	Min	25.75	25.78	25.90	26.08	26.20	26.33	26.48	26.73	29.25
		Max	30.23	30.15	30.10	30.28	30.78	31.25	31.43	31.95	34.13
		Mean	28.34	28.38	28.46	28.70	29.04	29.09	29.35	30.26	31.45
	Rainy	Min	24.75	24.70	24.68	24.63	24.68	24.65	25.00	27.40	26.50
		Max	32.03	32.08	32.10	31.98	31.90	31.85	31.88	32.00	31.50
		Mean	27.95	27.93	27.92	27.95	28.08	28.17	28.58	29.56	29.16
	Winter	Min	25.70	25.73	25.77	25.87	26.20	26.60	26.80	27.13	26.33
		Max	33.90	34.00	34.07	34.20	34.23	34.27	34.13	33.97	32.33
		Mean	30.02	30.05	30.05	30.10	30.17	30.32	30.53	31.37	29.33
Hydrogeo-logical unit	Young terrace deposits	Min	25.82	25.79	25.81	25.87	26.05	26.21	26.07	28.40	28.36
		Max	31.88	31.90	31.91	31.96	32.06	32.14	32.22	32.36	30.55
		Mean	28.87	28.89	28.92	29.02	29.20	29.21	29.64	30.67	29.52
	Old terrace deposits	Min	27.49	27.48	27.49	27.58	27.88	28.18	28.35	29.26	31.86
		Max	30.71	30.75	30.75	30.79	30.70	30.60	30.55	30.61	32.14
		Mean	28.68	28.69	28.70	28.79	28.94	29.08	29.23	29.94	31.95
	Flood plain deposits	Min	26.40	26.43	26.49	26.75	27.18	27.62	27.95	28.40	29.50
		Max	26.40	26.43	26.49	26.75	27.18	27.62	27.95	28.40	29.50
		Mean	26.40	26.43	26.49	26.75	27.18	27.62	27.95	28.40	29.50
Land use type	Building and village	Min	27.43	27.44	27.46	27.50	27.55	26.59	27.95	28.40	28.73
		Max	30.71	30.75	30.79	31.12	31.57	31.92	32.11	32.28	31.86
		Mean	29.18	29.20	29.24	29.35	29.51	29.52	30.08	30.36	29.98
	Agricultural land	Min	25.82	25.79	25.81	25.87	26.05	26.21	26.07	28.40	28.36
		Max	31.88	31.90	31.91	31.96	32.06	32.14	32.22	32.36	32.14
		Mean	27.96	27.96	27.98	28.08	28.31	28.46	28.66	30.13	30.12

potentiality, and land use is the first step to estimate the potential area for the vapor compression refrigeration system installation.

5. Conclusions

The study focused mainly on the groundwater temperature data and the factors influencing groundwater temperature changes. The average shallow and deep groundwater temperatures for various seasons, hydrogeologic units and land-use types had slightly different temperatures, and the temperature increased slowly with depth. The shallow and deep groundwater had temperatures below the atmospheric temperature.

The temperature-depth profile of shallow groundwater showed little variation in temperature below 2 m depth from the water table. The temperature-depth profile of deep groundwater showed that upper and lower zones of temperature were distinct. Mostly, the upper deep groundwater temperature-depth profile had a positive slope. The lower deep groundwater temperature was relatively constant. The seasons, hydrogeologic units, and land-use types had only little effect on the groundwater temperature in the Chiang Mai Basin.

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