台灣東北部礁溪地區溫泉開採對地下水溫度分布的影響

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摘要

本篇研究蒐集礁溪地區從 2011 年到 2014 年 10 口觀測井(M2~M11)測得的垂向地下水溫度，並利用深度 50 公尺的溫度分布將礁溪地區由溫泉湧出的中心至外圍每下降 10℃ 畫一區域，共分成 5 區(中心為區域 I，外圍為區域 V)。研究方法則運用 Mann-Kendall 方法來說明地下水溫度趨勢的變化，並得到兩個參數(S、P)。S 為 Kendall statistic，值如果為正表示溫度有變高的趨勢，反之亦然。P 為 probability，當 P 大於 0.3 時，表示維持現狀；當值介於 0.05 和 0.3 之間時，表示為可能的趨勢(possible trend)；當 P 小於 0.05 時，則代表顯著的趨勢(certain trend)。

本研究依 Mann-Kendall 方法的結果大致將礁溪地區地下水溫度變化為分兩部分。第一部分為區域 I、II，由觀測井 M2 為代表，M2 在淺層因靠近山區而降雨補注快速進而導致降溫，在 26~40 公尺有溫度增加的趨勢，但 46~80 公尺溫度則維持不變，推測其原因為抽水井的深度大多在 40 公尺以內，因此深部受到的擾動較小。第二部份為區域 III~V，由觀測井 M8~11 為代表，其有顯著降溫的趨勢，其原因可能為在區域 I、II 抽取大量地下水，使熱水流動的方向產生變化，故在礁溪外圍地區監測到的溫度會逐年遞減。因此，如果想要永續發展且在礁溪地區外圍也有足夠溫度的溫泉可以取用，應即時控管溫泉的抽取量，尤其是在溫泉湧出的中心地區。

關鍵字: Mann-Kendall、溫泉、宜蘭礁溪

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Subsurface temperature trends in response to thermal water exploitation in the Jiashi Hot Spring, northeastern Taiwan

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ABSTRACT

Temperature monitoring provides important information for the sustainable management of a geothermal field. Previous studies indicate that a decline in aquifer pressure is an obvious indicator of thermal water overexploitation. However, many thermal water producing aquifers display a subtle temperature change rather than a pressure decline. Due to the importance of monitoring temperature change, temperature detection is an important topic in the sustainable management of geothermal fields. In this study, we used borehole temperature-depth curves, obtained from boreholes measured over half-year intervals from 2011 to 2014, as well as the Mann–Kendall method, to determine trends for subsurface temperature within the Jiashi Hot Spring in Taiwan. Our results indicate that trends for subsurface temperature are related to hydrogeology and the flow field of groundwater. Groundwater/thermal water flow directions are impacted by the exploitation of thermal water in production wells, according to their depths and distributions, but pressure declines are not a dominant feature. Repeatedly measured borehole temperature-depths and their resultant curves provide important information for understanding trends in subsurface temperature change within a geothermal field.

1. Introduction

Temperature monitoring provides important information for the sustainable management of a geothermal field. Previous studies indicate that a decline in aquifer pressure is an obvious indicator of overexploitation in a thermal water producing aquifer (Duan et al., 2011; Rman, 2014). However, due to inflows of cooler water from surface recharge or the distal portion of an aquifer, many thermal water producing aquifers display a subtle temperature change rather than a pressure decline (Axelsson et al., 2010; Saar, 2011). Due to the importance of monitoring temperature change, temperature trend detection is an important topic in the sustainable management of geothermal fields (Lin et al., 2010; Ketilsson et al., 2010; Lopez et al., 2010; Szanyi and Kovacs, 2010; Mottaghy et al., 2011; Tian et al., 2015).

Initial subsurface temperatures are basically determined by local hydrogeology and the flow field of groundwater/thermal water. During the production stage of a thermal water producing aquifer, factors such as the depth of the production well, thermal water withdraw volume, and cooler water recharge have an impact on aquifer systems and changes in subsurface temperatures (Anderson, 2005; Haffen et al., 2013). In this study, we used borehole temperature-depth curves to identify dominant flow regimes in an aquifer and repeatedly measured temperature and depth over a half-year interval from 2011 to 2014 within the Jiashi Hot Spring (JHS) in northeastern Taiwan (Wilhelm et al., 2004; Teng and Koike, 2007; Erkan et al., 2008; Covington et al., 2011; Raymond et al., 2011; Xu et al., 2011; Read et al., 2013). Trends in subsurface temperature changes were identified using the Mann–Kendall (MK) method (Helsel and Hirsch, 2002; Helsel et al., 2006). Our goal was to detect trends in subsurface temperature changes, as well as the relationship between temperature change and the location and depth of production wells.

2. Hydrogeological background

In Taiwan, geothermal energy use occurs via direct-use, mainly for balneology in the 24 commercial spas and resorts that utilize hot springs (Fig. 1). The JHS, located within the northeastern coastal plain, is the most productive thermal water aquifer in Taiwan (Chang, 2000; Deng, 2007; Hsieh et al., 2008). Over 100 production wells and approximately 14,000 m^3 per day of thermal water, accounting for 22% of total production in Taiwan for 2009, are

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