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Groundwater-recharge connectivity between a hills-and-plains' area of western Taiwan using water isotopes and electrical conductivity

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SUMMARY

Water isotopes (δD, $\delta^{18}O$) as well as electrical conductivity were employed to clarify hydrological relationships among precipitation, stream water, and groundwater in the Douliou Hills (DLH) of Taiwan. They are also used to evaluate the importance of groundwater recharge sources in the proximal fan of Choshuichi alluvial plain (CSAP), which is connected to the eastern extreme of the DLH. Results indicate that the most important source of groundwater in the DLH comes from summer precipitation. In most cases the summer precipitation recharges stream water via base flow. Based on $\delta^{18}O$ and EC values, groundwater in the proximal fan of the CSAP can be divided into groundwater from 5 wells nearby the DLH (near-DHL group) and groundwater from 6 wells nearby the Choshui Stream (near-CS group). Semi-quantitative results calculated by ternary end-member mixing analysis (EMMA) for $\delta^{18}O$ and electrical conductivity values indicate that for the near-DLH group, precipitation in the CSAP contributes 40–50% of water to the proximal-fan groundwater while DLH groundwater donates 20–55% and Choshui Stream water, 0–29%. Precipitation in the CSAP is the most important recharge source. DLH groundwater's contribution is more notable in deep groundwater and Choshui Stream water's contribution decreases with distance from the Choshui Stream. For the near-CS group, anthropogenic pollution adds ions to the groundwater restricting the effectiveness of the ternary EMMA approach. This study provides new insights into groundwater recharge in the CSAP. It should be applicable to future studies of hill-and-plains' water connectivity in other regions.

1. Introduction

Groundwater is a vital water resource. During periods of adequate rainfall, it supplements surface water supplies; however, it often replaces surface water as the primary water resource during dry periods. In the 1970s, total water supply for Taiwan was about 10×10^8 m^3. Eighty percent of which was derived from surface water while the remaining 20% was sourced from groundwater (Wang et al., 2004). Since then, however, rapid economic growth and accompanying industrial expansion as well as population increase have greatly expanded water demand on Taiwan. By the 90s, yearly water consumption had grown to about 17.8×10^9 m^3. Thirty-one percent of this water comes from pumping groundwater. This equates to about 70×10^8 m^3 per year (Wang et al., 2004). This amount of pumped groundwater is much greater than Taiwan's annual groundwater recharge ($40–50 \times 10^8$ m^3) (Water Resources Agency, 2006). Consequently, groundwater management has become an important public policy issue for the island.

In this paper, a case study is made of water connectivity between a hills and plains region of western Taiwan (Fig. 1). The western side of the study area comprises a proximal-fan region of the Choshuichi alluvial plain (CSAP) while eastern side is a hills region called Douliou Hills (DLH). Water demand on the CSAP is high due to extensive agriculture and aquaculture. In fact, surface water has been inadequate and overdrawing of groundwater has induced consolidation of strata and land subsidence (Hsu, 1998; Chiang et al., 2005). Land subsidence has resulted in increasing groundwater salinity and deteriorating soil quality. Hsu (1998) suggested suitable groundwater management could remedy much of the environmental degradation. To achieve this, a proper understanding of the mechanics of groundwater recharge is an

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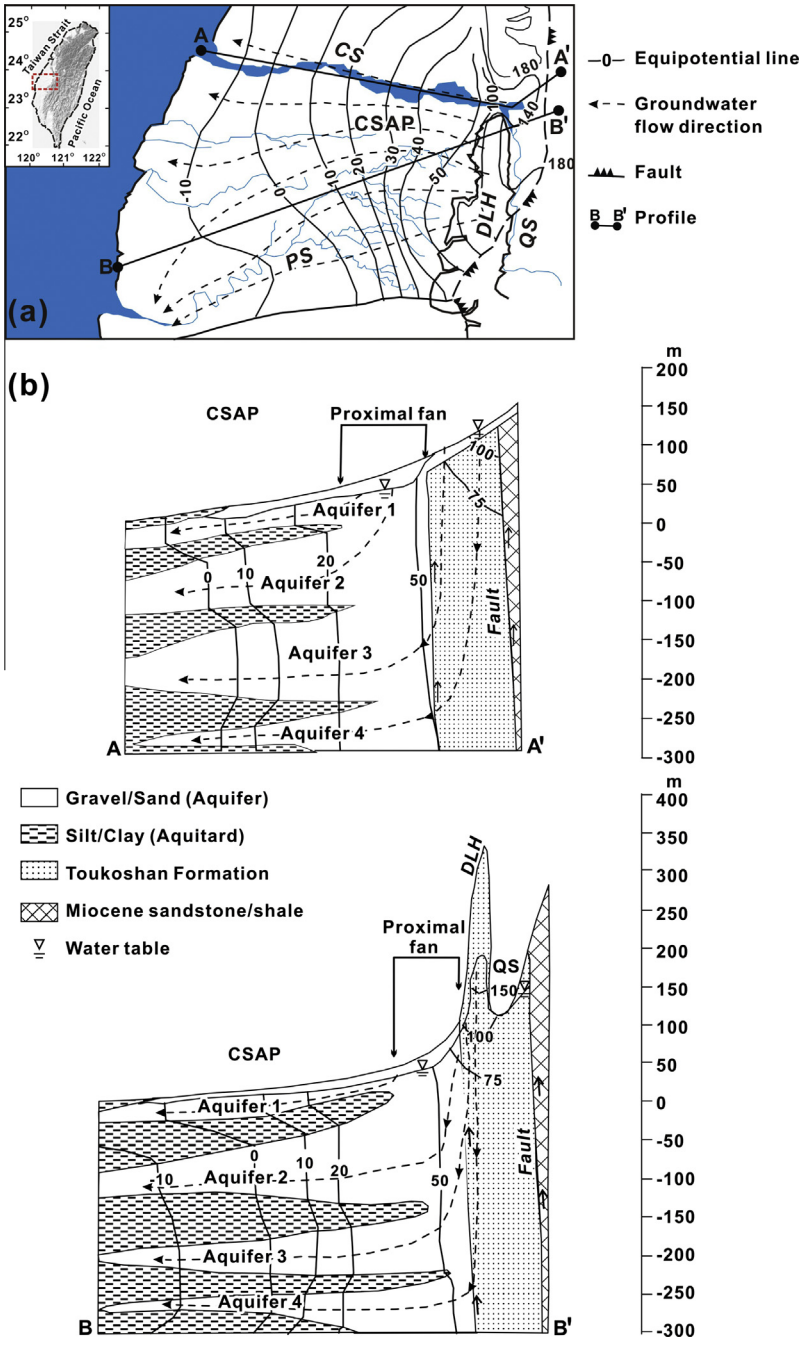

Fig. 1. (a) Map showing the Douliou Hills (DLH) and Choshuichi alluvial plain (CSAP). (b) Two profiles illustrating the hydrogeological characteristics of the CSAP (Chiang et al., 2005). Profiles show equipotential lines of groundwater. Shallow groundwater in the proximal-fan region recharges mid-level and deeper groundwaters, which recharge aquifers in middle- and distal-fan regions.

early-stage groundwater-management priority (Chiang et al., 2005). This includes appropriate assessments of the recharge region and recharge sources of groundwater, and amounts of available groundwater. Therefore, the main goal of this study is to identify groundwater sources of the Choshuichi alluvial plain. To accomplish this, the hydrological role of the Douliou Hills needs to be clarified (Fig. 1).

Using stable oxygen and hydrogen isotopes as natural tracers to identify and provide new insight into groundwater recharge has been very useful on a regional and local scale (e.g., Rozanski, 1985; Dafny et al., 2006; Peng et al., 2007, 2010a, 2012a, 2012b). The benefit of stable water isotopes in identifying water sources is that as natural tracers in a hydrological environment, they are conservative (Fritz, 1981; McCarthy et al., 1992). They can help differentiate water sources because their stable isotopic signatures are unique to the environments from which they are sourced due to different isotopic fractionation effects (Dansgaard, 1964; Yurtsever et al., 1981; Criss, 1999; Barth and Veizer, 2004).

Further, water's electrical conductivity (EC) is closely related to its concentration of dissolved ions (Appelo and Postma, 1996). This means EC may also be used as a tracer since conductivity differs from water source to water source. For example, deep groundwater always exhibits EC values higher than rainwater as groundwater experiences more rock–water interaction. Furthermore, polluted waters display higher EC values than non-polluted waters due to higher ion content. Therefore, like oxygen and hydrogen isotopes,