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Combining groundwater quality analysis and a numerical flow simulation for spatially establishing utilization strategies for groundwater and surface water in the Pingtung Plain

Cheng-Shin Jang [a], Ching-Fang Chen [b], Ching-Ping Liang [c], Jui-Sheng Chen [b,*]

[a] Department of Leisure and Recreation Management, Kainan University, Luzhu, Taoyuan 338, Taiwan
[b] Graduate Institute of Applied Geology, National Central University, Jhongli, Taoyuan 320, Taiwan
[c] Department of Environmental Engineering and Science, Fooyin University, Kaohsiung 831, Taiwan

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SUMMARY

Overexploitation of groundwater is a common problem in the Pingtung Plain area of Taiwan, resulting in substantial drawdown of groundwater levels as well as the occurrence of severe seawater intrusion and land subsidence. Measures need to be taken to preserve these valuable groundwater resources. This study seeks to spatially determine the most suitable locations for the use of surface water on this plain instead of extracting groundwater for drinking, irrigation, and aquaculture purposes based on information obtained by combining groundwater quality analysis and a numerical flow simulation assuming the planning of manmade lakes and reservoirs to the increase of water supply. The multivariate indicator kriging method is first used to estimate occurrence probabilities, and to rank townships as suitable or unsuitable for groundwater utilization according to water quality standards for drinking, irrigation, and aquaculture. A numerical model of groundwater flow (MODFLOW) is adopted to quantify the recovery of groundwater levels in townships after model calibration when groundwater for drinking and agricultural demands has been replaced by surface water. Finally, townships with poor groundwater quality and significant increases in groundwater levels in the Pingtung Plain are prioritized for the groundwater conservation planning based on the combined assessment of groundwater quality and quantity. The results of this study indicate that the integration of groundwater quality analysis and the numerical flow simulation is capable of establishing sound strategies for joint groundwater and surface water use. Six southeastern townships are found to be suitable locations for replacing groundwater with surface water from manmade lakes or reservoirs to meet drinking, irrigation, and aquaculture demands.

1. Introduction

Owing to limited surface water, groundwater is a critical water resource in the western and southwestern coastal areas of Taiwan. The Pingtung Plain has the lowest ratio of tap water use, approximately 45.8%, significantly less than the average in Taiwan, 92.7% (Taiwan Water Resources Agency [WRA], 2012), because of the abundant and inexpensive groundwater. However, a substantial amount of groundwater has already been extracted to meet drinking, irrigation, and aquaculture demands, leading to significant drawdown in overall groundwater levels and the occurrence of severe seawater intrusion and land subsidence over the past 5 decades (Ting et al., 1998). To solve the problem of the overexploitation of groundwater and the low ratio of tap water usage, the Taiwanese government plans to establish manmade lakes and reservoirs to increase the supply of surface water. Hence, the planning for utilization and management of groundwater resources is critical in the Pingtung Plain. Sustainable and reasonable groundwater utilization plan minimizing the impact of extraction on the groundwater levels that still meets the quality conditions of specified groundwater uses is proposed. This study integrates the concept of groundwater quality and quantity towards spatially exploring sustainable and reasonable groundwater use in the Pingtung Plain.

Groundwater typically contains a variety of natural and anthropogenic contaminants, so its quality is one of the most crucial factors affecting groundwater utilization for various purposes. For example, the use of the water with high concentrations of manganese (Mn) and iron (Fe) for purposes of agriculture or aquaculture may lead to retardation of growth or even the death of

* Corresponding author. Tel.: +886 3 2807427; fax: +886 3 4263127.
E-mail address: jschen@geo.ncu.edu.tw (J.-S. Chen).

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cultivated plants or fish (Tsai et al., 2006; Liao et al., 2008; Ye et al., 2009). The use of groundwater with high level of arsenic (As) is harmful to human health. Arsenic can also accumulate in crops and fish, posing an indirect threat to human health through ingestion (Huq and Naidu, 2005; Jang et al., 2006). It has been observed that employing water with high chloride (Cl^-) and sodium (Na^+) contents in irrigation can lead to toxicity and growth retardation in many crops (Grieve et al., 2006). Moreover, water with high levels of Cl^- and Na^+ is not suitable for drinking (D'Alessandro et al., 2008). Although nitrogen (N) compounds assist plant growth, irrigation water with high amounts of N can cause quality problems in some crops and excessive vegetative growth in certain vegetables (Bauder et al., 2007). Epidemiological evidence has indicated that long-term exposure to nitrate-N through the drinking water pathway is strongly associated with numerous diseases (Yang et al., 1998; Knobeloch et al., 2000). Clearly, the quality of groundwater extracted for use in the water supply needs to be carefully observed.

Typically there is considerable spatial variability in the parameters indicative of water quality. However, only a finite amount of field data has been surveyed because of constraints on funding, time, and resources. The spatial uncertainty of variables frequently results from limited observations; therefore, geostatistics has been widely adopted for spatially characterizing the variability and

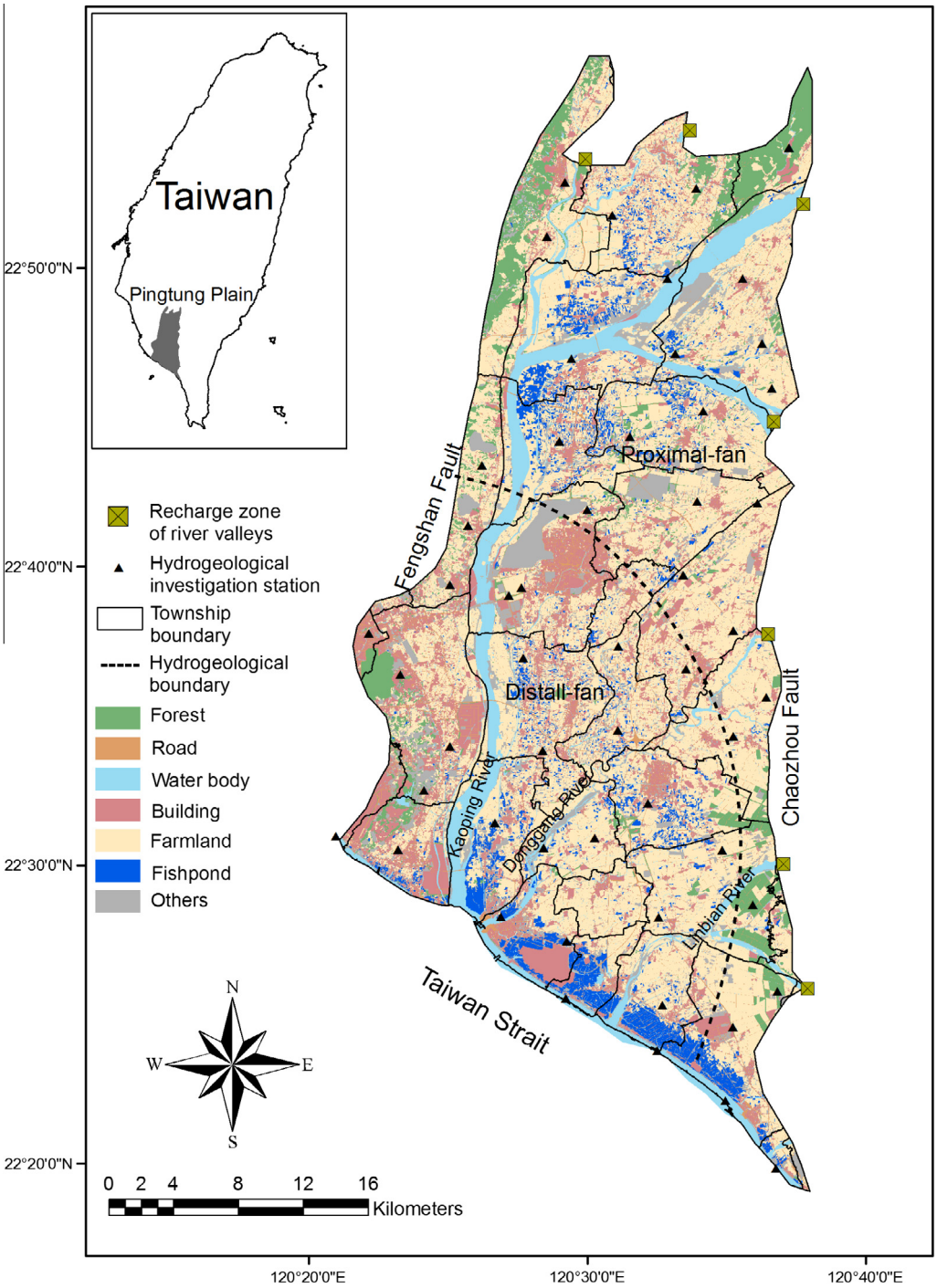

Fig. 1. Map of the study area.