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A novel technique for determining fresh-saltwater interface in coastal aquifer using pressure data

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1. Introduction

In coastal aquifers, the depth of fresh-saltwater interface varies due to natural and anthropogenic causes. The purpose of this study is to propose a simple method to determine the depth of fresh-saltwater interface in coastal aquifers using two sets of pressure data obtained from the freshwater and saltwater zones within a single borehole. This method is applied to estimate both short and long-term variations of the interface at the coastal aquifer on Jeju Island, Korea.

2. Theoretical background

Fig. 1 illustrates a simplified cross section showing fresh-saltwater interface that generally occurs in coastal aquifers. Two pressure transducers are installed at fresh and saline water zone and each device measures the ground water level with a pressure sensor, with the 'weight' of the water column above the instrument. Water levels h_1 and h_2 designate the depth of upper and lower pressure transducer from water level, respectively. The pressure from the upper transducer located at freshwater zone is P_1, and the pressure from the lower transducer located at saltwater zone is P_2. The pressure can be defined as:

$$P_1 = \rho_f g h_1 \tag{1}$$

$$P_2 = \rho_f g(h_1 + h_3) + \rho_s g h_4 \tag{2}$$

As $(h_1 + h_3) = (h_2 - h_4)$, Equation (2) becomes:

$$\frac{P_2}{g} = \rho_f (h_2 - h_4) + \rho_s h_4 \tag{3}$$

$$h_4 = \frac{1}{(\rho_s - \rho_f)}\left(\frac{P_2}{g} - \rho_f h_2\right) \tag{4}$$

$$h_2 = h_4 + h_3 + h_1 \tag{5}$$

where $P_2 = \rho_f g h_{2app}$, and h_{2app} is an apparent height of water column obtained from the pressure transducer installed at the saltwater zone.

Key words : coastal aquifer, fresh-saltwater interface, pressure, tidal fluctuation

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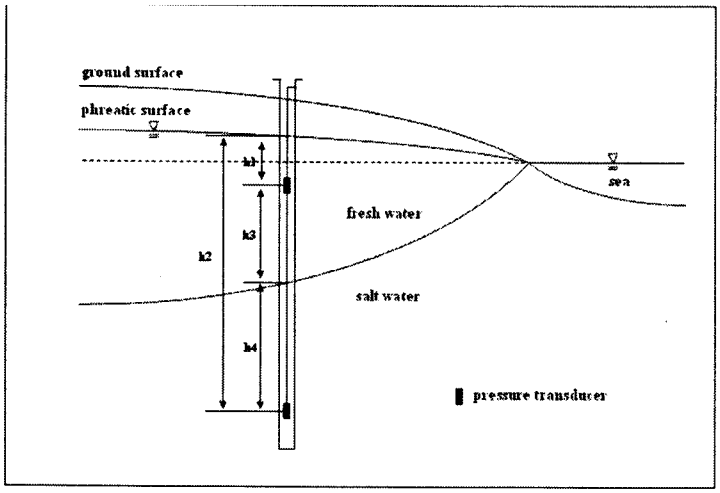

Fig. 1. A schematic diagram of fresh-saltwater interface in coastal aquifers and monitoring design of this study.

3. Applications

The pressure analysis method was applied to estimate the depth of the fresh-saltwater interface in the coastal aquifer located at the northern part of the island. The monitoring well, SC-1, has a depth of 90 m and is located at a distance of 320 m from the coastline. Two pressure transducers were installed in the SC-1 well at depths of 28 m and 84 m from the top of the casing. The pressure transducer used in this study was CTD-Diver with a respective accuracy and resolution of ±0.1% FS and 2 cmH_2O. All pressure data were measured at 30-minute intervals during a period of March 15-August 9, 2006. These data were compensated for barometric pressure.

EC profile was logged at low and high tides on March 13-14 and August 9-10, 2006. Since EC is temperature dependent, the measurements are expressed in relation to a reference temperature (25℃). A sharp and distinct interface was observed between the freshwater and saltwater zone. The EC was ~250 μS/cm in the freshwater zone and 25,000-31,000 μS/cm in the saltwater zone. The profile measured in March shows the interface located at a depth of ~40 m at the low tide and ~35 m at the high tide. The profile measured in August shows the interface shifted to the lower part of the well and the range of variation increased by the influence of tidal fluctuation. The location of the interface was at a depth of ~65 m at the low tide and ~46 m at the high tide.

Fig. 2(a) and (b) shows calculated fresh-saltwater interface on March 15 and August 9. The interface fluctuated between 34 and 40 m and between 46 and 60 m, respectively. Fig. 2(c) presents the result of the fresh-saltwater interface from March to August. A 50-point running average was applied to remove the effect of short-term tidal fluctuations.

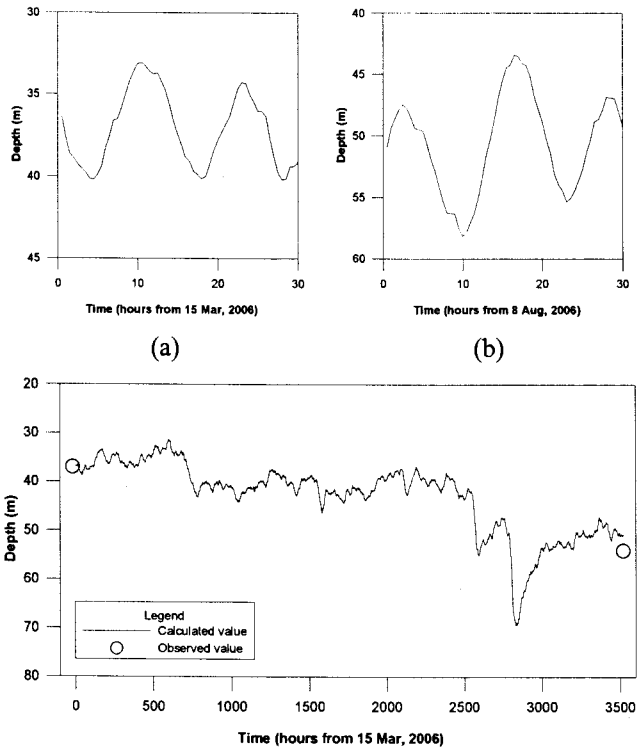

Fig. 2 Calculated fresh-saltwater interface for short and long term.

The interface was located around 35-45 m within narrow limits from March to June. Soon after a heavy rain on June 30, the interface declined sharply to a depth of ~55 m. Heavy rain on July 10 caused the interface to move to the lower part of the well to about 70 m depth. The deep located interface was recovered with time and was approximately 52 m in August.

4. Discussion and Conclusions

The pressure analysis method presented herein applies the density difference between freshwater and saltwater to estimate the location and variation of fresh-saltwater interface. This method can be applied at highly heterogeneous multi-layered subsurface system, and the calculated results reflect the temporal variations of tidal fluctuations and heavy rainfall. However, this method needs an assumption that the freshwater-saltwater interface is relatively sharp with a thin transition zone. Although the proposed method has some limitations in applying in the field, this new methodology has an advantage of simple and low cost technology. When continuous time series data is combined with a remote monitoring system, it may be used as an early warning system of the abnormal movement of saltwater into freshwater areas.