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Hydrogeochemical and geostatistical study of shallow alluvial groundwater in the Youngdeok area

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ABSTRACT

Multi-regression statistical analyses were applied for the water quality data of shallow alluvial ground waters (n = 47) collected from the Youngdeok area, in order to quantitatively generalize the natural (non-anthropogenic) causes of regional water quality variation. Seven samples having the high contamination index (C_a > 3) reflect the strong effects by anthropogenic activity. Most of the alluvial groundwaters have acquired their quality primarily due to the dissolution of carbonate minerals. The results of multi-regression analysis show that chlorine is mainly derived from seawater effect. Sulfur isotopic compositions of dissolved sulfate and the SO_4/Cl ratio also enable us to discriminate the samples (n = 18) which are affected by atmospheric input of marine aerosol (sea-spray) and also by mixing between freshwater and seawater. Hydrogen and oxygen isotope data of the samples collected lie close to the local meteoric water line obtained from nearby Pohang city but has lower slope (5.45) on the $\delta D-\delta^{18}O$ plot, indicating that alluvial groundwater was recharged from infiltrated meteoric water which has undergone some degree of kinetic evaporation. The estimated initial isotopic composition of the recharged water (δD = -74.8‰, $\delta^{18}O$ = -10.8‰) suggests that the alluvial ground water recharge largely occurs during summer storm events.

Key words: shallow alluvial ground water, Youngdeok area, hydrogeochemistry, environmental isotopes, multi-regression statistics, contamination index, sea spray, evaporation

I. Introduction

Various factors such as the recharged rainwater composition, aquifer material, flow path, hydraulic conductivity, and inputs of anthropogenic pollutants affect the chemistry of shallow alluvial groundwater. The understanding of the effect of each factor in water quality is very important for the sustainable management of an alluvium aquifer, but it is usually very difficult. To know the contribution of a particular variable we should limit remaining other variables. Especially for regional, sparsely located water samples, however, the restriction of a variable is not so easy because of the individualization of the samples and the combined effects of hydrochemical processes among the dissolved ion species. In the regional water quality survey under such cases, the adaption of multi-regression analysis technique is very useful to evaluate quantitatively the complicatedly combined variables.

Alluvial ground waters become very important to water supply in Korea. However, available informations on regional water quality are scarce. In this study, we have collected and analyzed shallow alluvial ground water samples (n = 47) along the major streams in the Youngdeok-Kun area in the southeastern coastal district of Korea. The main purposes of this study are: (1) to evaluate the contribution of diverse natural (non-anthropogenic) sources to regional water quality variation, (2) to understand the effects of sea water intrusion and/or sea spray in ground water quality, and (3) to evaluate the degree of anthropogenic contamination. For these purposes we used various data interpretation techniques including the calculation of contamination index (C_a), the application of multi-regression techniques, and the environmental isotope analyses.

II. Spatial Water Quality Variation

The spatial distribution of major ionic species seems to very irregular in the Youngdeok area. However, at least two patterns are recognized. For the samples collected along the Osip-cheon stream, increased concentrations of Na and Cl are recognized at downstream and coastal sites. In such places, the molar Na/Cl ratio approaches to unity. Among the ionic species, the spatial variation of the concentrations of Ca, Mg and HCO_3 as well as their relative proportions is similar. These three ions reflect their predominantly natural origin, due to the dissolution of carbonate minerals (calcite, dolomite) in aquifer.

We calculated the contamination index for each samples, in order to pick out heavily contaminated samples. According to Backman (1997; Environmental Geology), the contamination index (C_a) can be calculated by the following simple equations.

$$C_{fi} = \frac{C_{Ai}}{C_{Si}} - 1 \quad \text{(eq 1)}$$

$$Z_{fi} = \frac{C_{fi} - \overline{C_{fi}}}{\sigma} \quad \text{(eq 2)}$$

$$C_a = \sum_{i=1}^{n} Z_{fi} \quad \text{(eq 3)}$$

(Here, C_a = anthropogenic contamination index; C_{fi} = contamination factor for the *i*-th element/compound; Z_{fi} = standard score for the *i*-th element/compound; $\overline{C_{fi}}$ = the mean of the contamination factor for the *i-th* element/compound; C_{Ai} = analytical value of the *i*-th element/compound; C_{Si} = Korean drinking water standards for the *i*-th element/compound; and σ = standard deviation of *i-th* element/compound).

Seven samples with high contamination index ($C_a > 3$) were identified. They are distributed mainly in the downstream areas of the Song-cheon and Chucksan streams. The Song-cheon stream runs through an wide ricefield, whereas the Chucksan stream flows through both cornfield and inhabitable areas. Therefore, the ground water pollution in Youngdeok area occurs mainly due to agricultural fertilizer and manure in addition to septic tanks and domestic sewage from adjacent villages.

III. Non-anthropogenic Sources of Water Quality Variation: Multi-Regression Statistical Analysis on Seawater Effects

As described above, the Na and Cl concentrations in alluvial ground waters appear to increase toward downstream and near-coastal sites. This trend indicates the contribution of seawater to water quality. However, the sources of Na and Cl may be diverse in addition to seawater source. In order to correct the effect of various ions in the regional distribution pattern of Na and Cl, stepwise regression analysis were applied to the logarithmic values of all the ion concentrations. The heavily polluted, seven samples were ruled out in this analysis. The logarithmic Na and Cl concentrations were set up as dependant variables, whereas other ion concentrations as independent variables. The following two equations were derived for the theoretical calculation of Na and Cl concentrations.

$$\log Cl = 0.631 + 0.771 \log Na + 0.721 \log Mg - 0.485 \log HCO_3 \quad \text{(Eq 4)}$$

$$\log Na = -0.633 + 0.764 \log Cl + 0.674 \log HCO_3 - 0.500 \log Mg \quad \text{(Eq 5)}$$

By examining the spatial distribution of corrected chlorine values ($\Delta \log Cl = \log Cl_{analysed} - \log Cl_{calculated}$), we can evaluate quantitatively the contribution of seawater. The corrected chlorine values appear to increase toward the seaside, whereas the corrected sodium value ($\Delta \log Na = \log Na_{analysed} - \log Na_{calculated}$) tends to decrease toward the aquifers located at southern part in Youngdeok area. These results indicate that the chlorine source is largely seawater (via the direct diffusive intrusion and/or the sea-spray), whereas the sodium ion has diverse sources in addition to seawater. The inland source of Na is likely the dissolution of sodium-bearing silicates. We may consider that the difference in characteristics of aquifer materials may explain the distribution of corrected sodium concentrations.

IV. Recharge Characteristics: Environmental Isotope Studies

We have analyzed sulfur isotope compositions of dissolved sulfates in 12 samples. The $\delta^{34}S$ values (relative to CDT) fall in the narrow range from 4.2 to 9.3 ‰, except only two samples (YS-07 and YS-17) with $\delta^{34}S$ values of -7.7 and 16.8‰, respectively. The $\delta^{34}S$ value of the sample YS-17 approaches the seawater $\delta^{34}S$ value (21‰). The range (about 4 to 9‰) for most samples likely suggest the derivation of sulfur from pyrite (igneous) in aquifer materials.

The SO_4 versus SO_4/Cl diagram (Fig. 1) for analyzed samples (n = 49) shows that two samples YS-17 and YS-43 plot along the direct mixing line between rain water and ocean water. The Group 1 waters (n = 16; encircled in Fig. 1) have the short distance (average 1.6 km) from the coast, whereas the Group 2 waters are distant (avg. 4.9 km) from the coast. It is clear that the chemistry of Group 1 waters are more strongly influenced by indirect input of seawater such as marine aerosol (sea-spray).

In order to understand the recharge characteristics of alluvial ground waters, we analyzed oxygen and hydrogen isotope compositions of 10 water samples (Fig. 2). The local meteoric water line (LMWL) was obtained by KAERI through the past 16-year collection of rain waters in the nearby Pohang city. On the δD-δ

^{18}O plot (Fig. 2), alluvial ground waters plot below the LMWL and have a low slope (5.45) of the regression line. This indicates that alluvial groundwater in Youngdeok area was recharged from infiltrated meteoric water which has undergone kinetic evaporation. The intersection point (δD = −74.8‰, $\delta^{18}O$ = −10.8‰) between the LMWL and the alluvial ground water line may represents the isotopic composition of the recharged water, and suggests that the ground water recharge occurs largely during summer storm events.

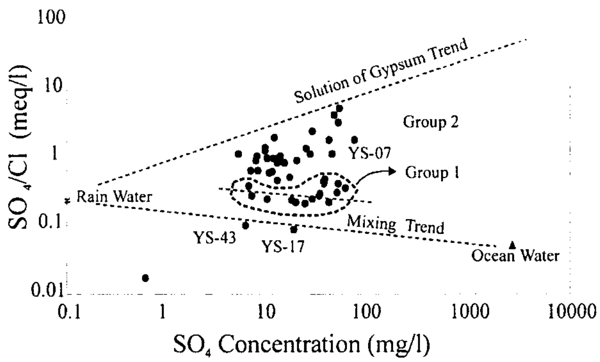

Fig. 1. SO_4 concentration versus SO_4/Cl ratio diagram for shallow ground waters of Youngdeok area.

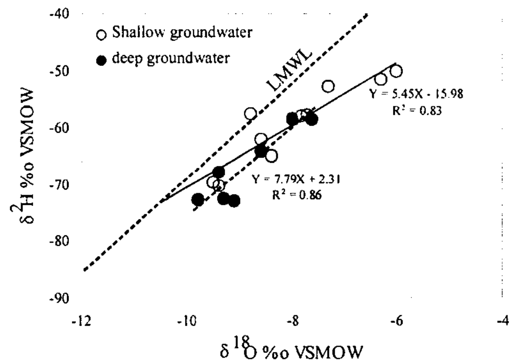

Fig. 2. Oxygen and hydrogen isotope diagram for shallow ground waters in Youngdeok area. For comparison, data of deep ground waters are also shown.

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