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An integrated studies for salt-water intrusion in Yeonggwang-gun, Korea

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Abstract: A combination of drilling, hydrogeochemical survey, geophysical survey and the numerical modelling for the flow and transport of groundwater was performed to evaluate the seawater intrusion in Baeksu-eup, Yeonggwang-gun, Korea. The survey area extends to over 24 km^2. Twelve wells were also drilled for the collection of geologic, geochemical, hydrologic, and geophysical logging data to delineate the degree and vertical extent of seawater intrusion. To evaluate and map the salinity in a coastal aquifer, geophysical data and hydrogeochemical results were used. Layer parameters derived from VES data, various *in situ* physical properties from geophysical well loggings, and the estimated equivalent NaCl concentration were used as the useful input parameters for the numerical simulation with density-dependent flow. Our multidisciplinary approach for evaluating the seawater intrusion can be considered as a valuable attempt to enhancing the utilization of various data and the reliability of numerical ground modelling.

1. Introduction

A seawater intrusion deteriorating the water quality of coastal aquifer mainly occurs along the western and southern seashores in Korea. Hwang et al. (2003) reported that about 47 % of groundwater wells within 10 km from the western and southern seashores are affected by the seawater intrusion. The seawater intrusion is a problem to be solved inevitably in countries adjacent to the sea. In order to develop a technique for assessing the seawater intrusion, multidisciplinary approach is necessary. In this study, we have performed the various survey including drilling, geophysical and hydrological survey, and numerical modelling for rather quantitative analysis.

2. Geologic setting of survey area

The survey area is located in Baeksu-eup, Yeonggwang-gun, the western seashore of Korea. The topography is generally plain as shown in Fig. 1. The central area mainly consists of paddy and dry fields. The western side is adjacent to the sea, while the north eastern side is a mountainous part containing Gaji-san with an altitude of 50 m. The survey area is about 24 km^2. Drilling results show the geological columns resulted from 12 drillings, which indicates that the geological structure of the survey area comprises mud (the surface to depth of 5-20 m), sand (about 25 m), and bedrock granite layers (below approximately depth of 25 m).

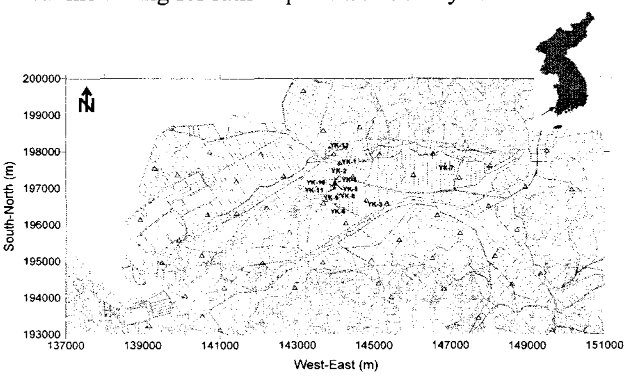

Fig. 1. Location map showing boreholes (open circle) and VES stations (solid triangle) superimposed on the topographic map of survey area.

3. Vertical electrical soundings

Vertical electrical soundings (VES) were carried out over 60 stations to understand the geological structure of the survey area (see Fig. 1), where Schlumberger electrode array was used and the maximum current electrode spacing was 150 m. From the surface to depth

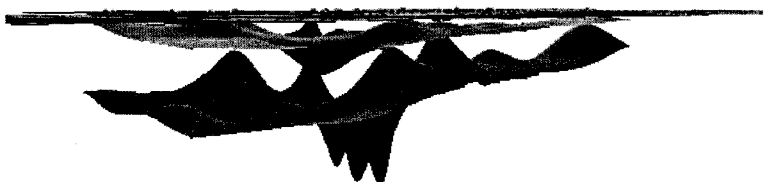

Fig. 2. Three-dimensional view of the layer boundary interpreted from VES data (1:50 vertically exaggerated).

of about 4 m, there is alluvial layer, the interval of lowest resistivity indicates mud, the depth of about 14 - 27 m corresponds sand, and we can see highly resistive bedrock granite layers (below about 27 m). A three-dimensional view of layer boundaries interpreted by compiling the inversion results of VES data is shown in Fig. 2, where the ratio of horizontality to verticality is 1:50. The left side of the Fig. 1 and that of the Fig. 2 are the same.

4. Geophysical log analysis

Various geophysical well loggings, such as temperature, fluid conductivity, electromagnetic induction, caliper, natural gamma, gamma-gamma and thermal neutron logging were obtained in 12 boreholes for analysing the hydrogeologic characteristics and for calibrating the surface geophysical data. The results of geophysical well logs in boreholes YK-4 and YK-8, which are located near the center of survey area as shown in Fig. 1 show that the resistivity in the sand layer is less than 10 ohm-m, and the electrical conductivity of fluid is more than 5,000 μS/cm. The thermal neutron loggings were carried out in boreholes YK-4 and YK-8 to estimate the formation porosity and the electrical conductivity of pore water of the sand layer. The average porosity of the sand layer was about 38 %. The electrical resistivity of pore water in the sand layer was obtained using the Archie's law (Archie, 1942).

5. Distribution of salinity in the sand layer interpreted using the geophysical data

The VES results were used to map the salinity and to find the seawater/freshwater interface in the sand layer, the main aquifer in the survey area. The salinity and seawater/freshwater interface in the sand layer could also be estimated more quantitatively if we express the resistivity of groundwater in terms of the concentration of dissolved salts in the aquifer. So we could transform the resistivity of groundwater the main aquifer as an equivalent *NaCl* concentration. The relation between the resistivity and the equivalent *NaCl* concentration in the survey area was derived from the analysis of cations and anions of ground water within the survey area. Fig. 3 shows the contour map of the estimated equivalent *NaCl* concentration in the sand layer of the survey area. The seawater/freshwater interface is almost along North-South to slightly east direction at the center of the survey area when the electrical conductivity of brackish water is assumed to be 2000–8000 μS/cm. The distribution of equivalent *NaCl* concentration in Fig. 3 can also be used as the input data (i.e., density distribution of groundwater) for numerical fluid flow modelling of seawater intrusion.

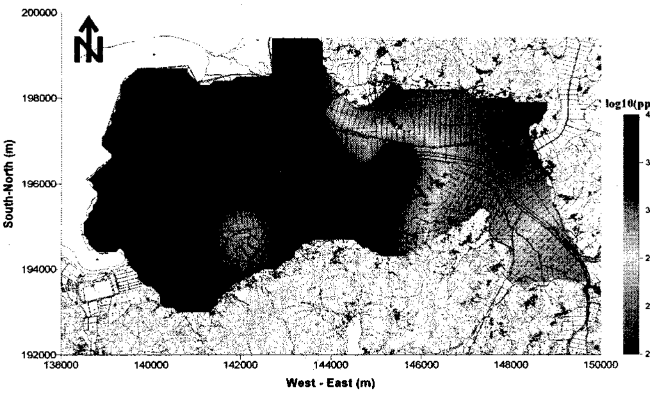

Fig. 3. Contour map of estimated equivalent *NaCl* concentration in the sand layer. The unit of contour is ppm.

6. Hydrogeochemical survey

Hydrogeochemical and stable isotope studies were carried out to understand the distribution of saline groundwater, origin of salts and seawater mixing ratios of groundwater from the detailed survey area. The most common water types are found to be Na-Cl and Na-Cl-HCO_3 in saline aquifer, and groundwater can be divided in the fresh (58.8%), brackish (19%) and salt (22.2%). Fig. 4 is the chloride concentration in the saline aquifer. Hydrogeochemical parameters (Na-Cl, Cl/∑anion, HCO_3//∑anion, Na/(Na-Cl) and stable isotope techniques (δD, $\delta^{18}O$) were used to identify sources of salts in saline groundwater (Fig. 5). The results revealed that salinity of saline groundwater is caused by the concentration of dissolved salts by seawater intrusion.

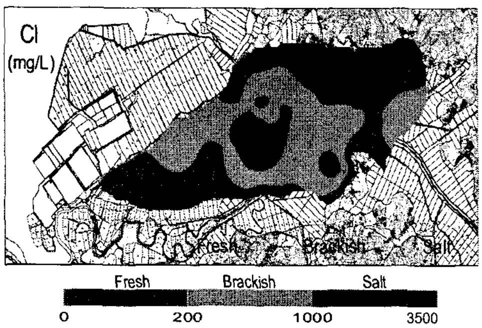

Fig. 4. Distribution of brackish and salt water.

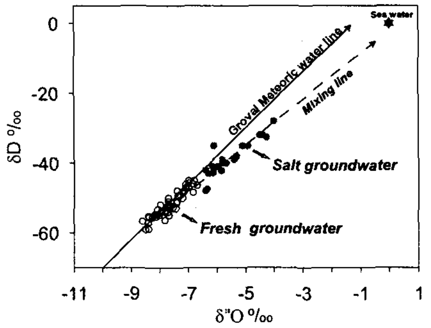

Fig. 5. δ D-δ^{18}O diagram showing the isotope fractionation effect of fresh groundwater toward seawater.

The freshwater-seawater mixing curve [Mixing ratio (vol.%)=$0.08\times\delta^{18}O-8$] was obtained from two end members of mean δ^{18}O values of fresh groundwater and seawater in the laboratory works. The mixing ratios of groundwater range from 0 to 30%, dominantly less than 10 % and seasonal variations of their distributions are shown in Fig. 6.

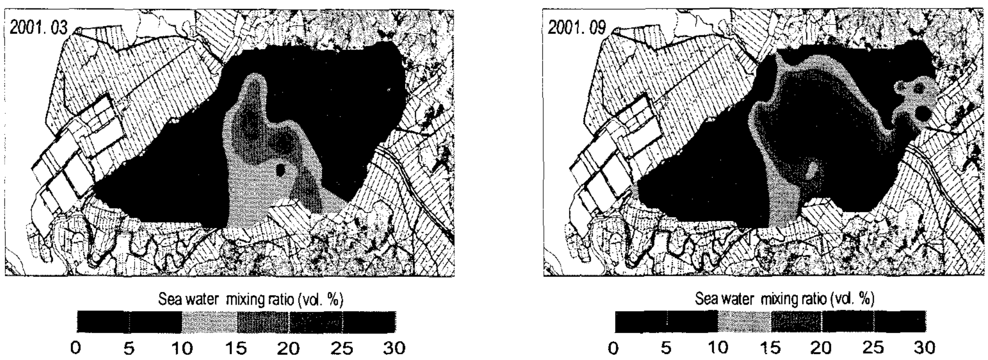

Fig. 6. The seasonal variations of seawater mixing ratio (vol. %).

7. Numerical modelling for the flow and transport of groundwater

For the numerical simulation of the problem with density-dependent flow, the computer code SWIFT II (Sandia Waste-Isolation Flow and Transport Model, 1986) and Groundwater Vistas (2001) as a pre-processor were used. We set the no-flow boundary condition first, which describes northern, eastern, and southern hills. Usage of this water divide boundary significantly simplifies a relatively complex aquifer problem. The hydrogeologic system concerns three aquifers. The top hydrostratigraphic unit is considered to be a clay, unconfined aquifer. The sandy aquifer located below the clay has a thickness of about 25 m as shown in Fig. 2. The salinity concentration map in Fig. 3 was used the initial condition for the flow and transport of groundwater.

Using the obtained from drilling, geophysical and hydrological data, numerical simulations were conducted for three cases (Case 1: no production well, Case 2: measured total production rate of 2,397 m^3/day in 10 production wells, Case 3: 10 times of case 2) in order to observe the effect of production wells. Computed concentration fields of case 2 were hardly changed after 10 years. It was thought that the measured production rate of this area is too low comparing with recharge rate (20,000 m^3/day). However, increased production rate could accelerate the saltwater intrusion through the clay and sandy layers as shown in Fig. 7.

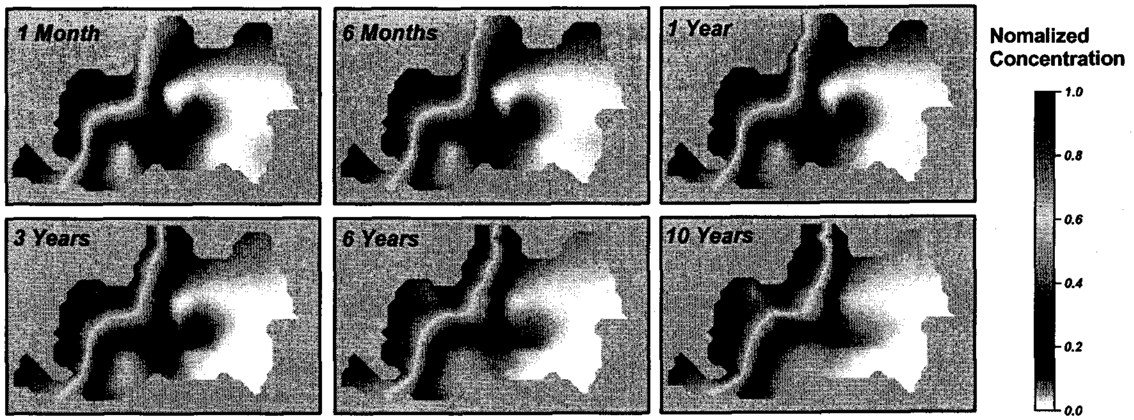

Fig. 7. Normalized brine concentration of sandy layer for case 3.

8. Conclusions

The multidisciplinary approach for evaluating the seawater intrusion is greatly promising because of the reliability to estimate the distribution of water quality and to perform the numerical modelling.

In this study, we have performed VES and drilling to identify the subsurface geology, the geophysical well logging to evaluate the formation characteristics, and hydrogeochemical survey to verify the origin of salinity of groundwater. From the VES and drilling, we have mapped the subsurface geology of survey area and provided the geologic information as a simplified model to numerical modelling for flow and transport of groundwater. Various physical properties obtained from geophysical logging are useful to estimate the pore water resistivity in the sand aquifer. From equivalent *NaCl* concentration of sand aquifer estimated by geophysical data and hydrogeochemical analysis, we could quantitatively map the salinity and evaluate the seawater/fresh water boundary in a sand layer. The distribution of equivalent *NaCl* concentrations can also be used as the input data (i.e., density distribution of groundwater) for numerical fluid flow modelling of seawater intrusion. Our integrated studies for evaluating the seawater intrusion can be considered as a valuable attempt to enhancing the utilization of various data and the reliability of numerical ground modelling.

Acknowledgement

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