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title: **Identification of groundwater salinization at the Suyeong county in the Busan city, Korea**

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INTRODUCTION

The Busan Metropolitan City is the 2nd large city in Korea and is located at the coast. Generally, groundwater use is restricted by seawater intrusion at the coastal area. Groundwater is contaminated by seawater intrusion at the coastal area in Busan. The population of Busan is 3.7 million. The city has many tunnels for three subway lines, for communication cables and for electrical cables under the ground. Groundwater discharge from the tunnels is very serious. The groundwater level is drawdowned especially around the subway lines, and the groundwater quality is deteriorated by the inflow of seawater or river water derived from the groundwater discharge. So many groundwater wells around subway tunnels have been abandoned because of the reduction of quantity or the contamination of quality.

In this study, the cause for the deterioration of groundwater quality is identified by several investigations and analyses at a coastal area at the Suyeong District in the Busan Metropolitan City. Research methods include the investigations of groundwater level and quality of wells, quantity and quality of groundwater discharged from subway, quality of river water, and geostatistical analysis of groundwater level and quality data.

MATERIALS AND METHODS

Hydrogeological settings

The study area includes the Suyeong District in the Busan Metropolitan City. The Kwanganri Beach is located at the southeastern side of the Suyeong District (Figure 1). The Suyeong River is located at the eastern side, and is connected to the sea. The geology of the study area is composed of andesitic volcanic breccias, tuffaceous sedimentary rocks, rhyolitic rocks, and intrusive granodiorites and granite porphyries (Chang et al., 1983; Son et al., 1978). The geologic time belongs to the Cretaceous Period in the Mesozoic Era.

Alluvial deposit is developed around the Kwanganri Beach, and groundwater is relatively vulnerable to seawater intrusion. However, the coastal area of crystalline rocks is not highly influenced by seawater intrusion.

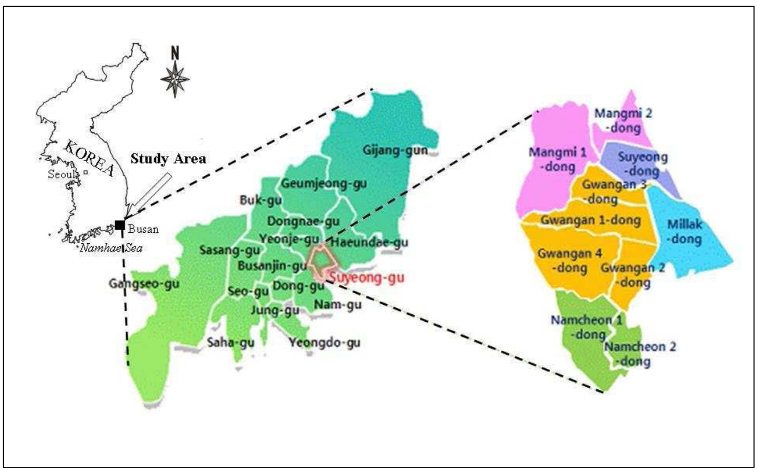

Figure 1. Administrative districts of the study area.

Groundwater samples and analysis

Groundwater was sampled at 135 wells developed in shallow and deep aquifers, and the samples were relatively uniformly distributed at the study area. However, many groundwater samples couldn't be collected at the west side of the study area because there is no groundwater wells at Mt. Kumryeon. Temperature, pH, Electrical Conductivity (EC), Oxidation-Reduction Potential (Eh), Dissolved Oxygen (DO) and Alkalinity were measured in the field. Seven major elements, five minor and trace elements were analyzed in the laboratory using Atomic Absorption Spectrometer (AAS), Ion Chromatography (IC) and Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES). Piper's trilinear diagram was used for the classification of groundwater quality type.

Geostatistical analysis

For geostatistical analysis, ordinary kriging was used to produce distribution maps for groundwater level and groundwater quality in this study. Kriging is a local estimation technique of the best linear unbiased estimator (BLUE) for the unknown values of spatial and temporal variables (Journel and Huijbregts, 1978). Kriging is expresses as

$$Z_K^* = \sum_{i=1}^{n} \lambda_i Z_i \tag{1}$$

where Z_K^* is an estimated value by kriging, λ_i is a weight for Z_i, and Z_i is a variable value. The weight is determined to ensure that the estimator is unbiased and that the estimation variance is minimal.

The unbiased condition of kriging is

$$E\{Z_V - Z_K^*\} = 0 \tag{2}$$

where Z_V is an actual value and Z_K^* is an estimated value.

The sum of weights is

$$\sum_{i=1}^{n} \lambda_i = 1.0 \tag{3}$$

The estimation variance of kriging variance is

$$\sigma_K^2 = E\left\{\left[Z_V - Z_K^*\right]^2\right\} = \overline{C}(V,V) + \mu - \sum_{i=1}^{n} \lambda_i \overline{C}(v_i, V) \tag{4}$$

where $\overline{C}(V,V)$ is covariances between sample variables, μ is Langrange parameter and $\overline{C}(v_i, V)$ is covariances between sample variable and estimates.

RESULTS AND DISCUSSIONS

Groundwater use

The number of groundwater well is 377 at the study area. The quantity of groundwater use could not be examined at 71 wells. The total uses of groundwater are 1,531,000 m^3/year (4,243 m^3/day) at the study area. The quantity for living use is 1,356,684 m^3/year (3,760 m^3/day), and 89% of total uses.

Groundwater discharge from subway tunnels

2,057 m^3/day (751,000 m^3/year) of groundwater is discharged from the subway at the study area. 67 m^3/day (24,500 m^3/year) of discharged groundwater is used for living and washing uses, the rest is sent directly to the river. Table 1 shows that the sustainable development yield of groundwater is 951,000 m^3/year, and total quantity of discharged groundwater from the subway and used groundwater is 2,282,000 m^3/year at the study area. So the total quantity of discharged groundwater from the ground is 2.4 times the sustainable development yield of groundwater. So the groundwater level is decreased at the study area.

Table 1. Groundwater use and discharge at the study area (unit: m^3/year).

Sustainable development yield	Groundwater use	Groundwater discharge from the subway	(Groundwater use + Groundwater discharge)/(Sustainable development yield)
951,000	1,531,000	751,000	240 (%)

Source: MLTM and KWRC (2007, 2008), BTC (2007).

Groundwater level distributions

The groundwater levels of 135 wells were measured on December, 2007 and July, 2008. The average groundwater level is 7.81 m above the mean sea level in dry season, and 9.11 m above the mean sea level in wet season. The difference between dry season and wet season is about 1.3 m.

The distribution maps of groundwater level were produced using a geostatistical method (Robertson, 2004). Figure 2 and 3 shows groundwater level distributions in dry and wet seasons, respectively. The groundwater levels are located below the average sea level. The minimum groundwater levels in dry and wet seasons are -32.32 m and -30.37 m below the mean sea level, respectively.

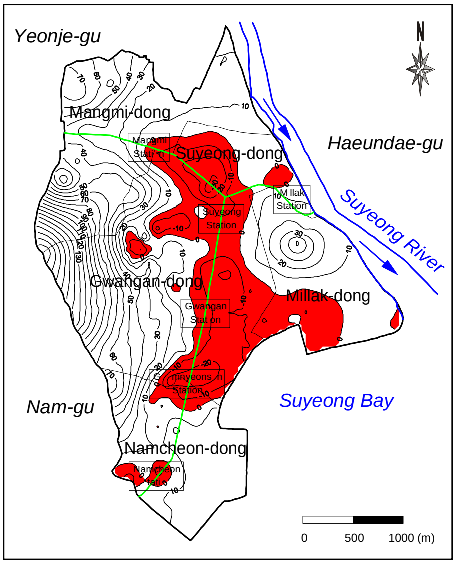

Figure 2. Distribution map of groundwater level (Dry season).

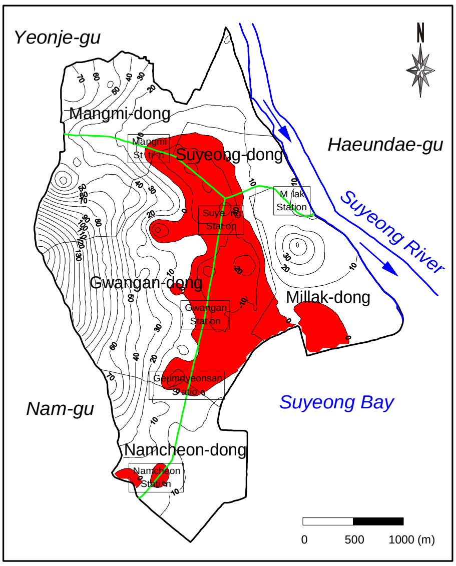

Figure 3. Distribution map of groundwater level (Wet season).

Groundwater quality distributions

The average water temperature of wet season is 5.5°C higher than that of dry season. The average of pH is 0.4 higher, and the average of DO is 0.6 mg/L lower in wet season. The average of EC is 136 µS/cm higher in wet season.

Figure 4 and 5 show the distributions of EC in dry and wet seasons, respectively. The higher EC over 800 µS/cm (red color zones of Figure 4 and 5) is formed around the subway lines and the

Suyeong Bay. It is the result of seawater intrusion derived from the drawdown of groundwater level around the subway lines. The water of the Suyeong River also comes into the Millak subway station because of the groundwater discharge from the subway. By the way, the Suyeong River is salinized by the seawater. The salinized river water contaminates the original groundwater around the Millak subway station.

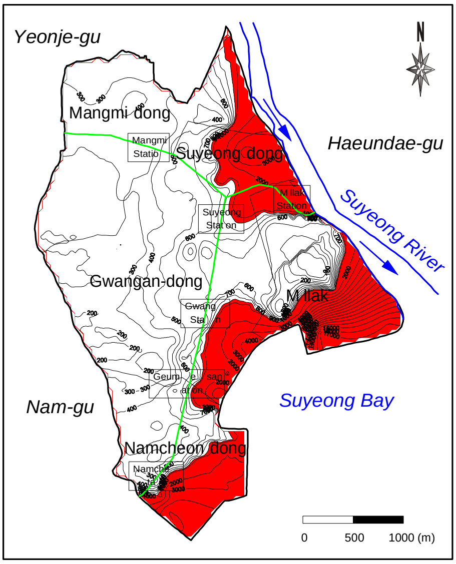

Figure 4. Distribution map of EC (Dry season).

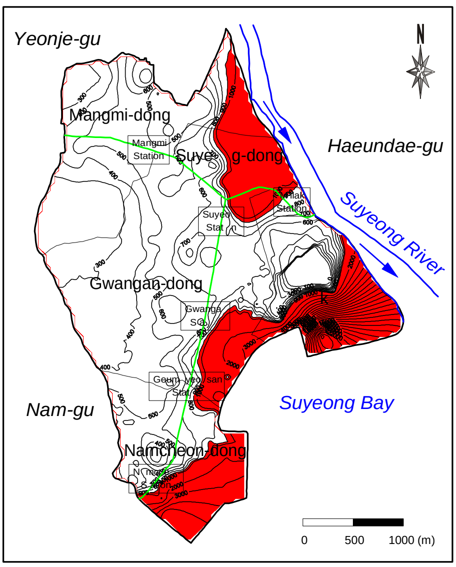

Figure 5. Distribution map of EC (Wet season).

Seawater impact to the Suyeoyng ang Oncheon rivers

The Suyeong River is the largest river in Busan, and is connected to the sea. It is affected by tide, and is salinized by seawater. The EC of the Suyeong River reaches to 32,000 μS/cm in dry season, and to 15,000 μS/cm in wet season. The influence of seawater is to 5.5 km distance from the Suyeong Bridge. The EC of the Oncheon Stream reaches to 23,000 μS/cm in dry season, and to 12,000 μS/cm in wet season . The influence of seawater is to 1.5 km distance from the cross point of two rivers.

Quality and quantity of groundwater discharged from subway

The quantity of discharged groundwater is measured using a TLC meter, and ranges from 232 to 545 m^3/day during 7 months. The quality of discharged groundwater belongs to NaCl type (Table 2). It proves that the water of the Suyeong River infiltrates the Millak subway station.

Table 2. Quality of groundwater discharged from the Millak subway station.

Cations	Concentration (mg/L)	Anions	Concentration (mg/L)
Ca^{2+}	157.70	HCO_3^-	578.30
Mg^{2+}	101.50	Cl^-	1,878.00
Na^+	682.20	SO_4^{2-}	312.00
K^+	52.30	CO_3^{2-}	0.00
NH_4^+	1.43	NO_3^-	7.50

CONCLUSIONS

The total quantity of discharged groundwater from the ground is 2,282,000 m^3/year at the study area. It is 2.4 times the sustainable development yield of groundwater. So the groundwater level is seriously decreased at the study area. The groundwater level around the subway is located at 30 ~ 32 m below the mean sea level. The deep drawdown of groundwater level brought about the inflow of seawater and river water. By the way, the Suyeong River is salinized by seawater, because it is connected to the sea. Therefore, the groundwater around the subway lines is contaminated by seawater and salinized river water. The quality of groundwater doesn't reach to the standard of potable, domestic, agricultural and industrial uses.

The distribution maps of groundwater level and quality were produced using a geostatistical method, i.e., kriging. The maps were very useful to find out the problems of groundwater at the study area. The maps identified that the sea water and river water infiltrated the inland groundwater and contaminated the groundwater around the subway lines.

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