論 文 の 内 容 の 要 旨

論文題目　Numerical analysis of variable-density flow and mass transport in unsaturated-saturated media: prediction of seawater intrusion problem under future tsunami scenarios at the Niijima Island, Japan
（地下の飽和−不飽和領域における密度流・物質輸送に関する数値解析的研究：新島における将来的な津波被害に伴う地下水の塩水汚染の予測を事例として）

氏　　名　劉 佳奇

Tsunamis cause vertical infiltration of seawater from land surface to coastal aquifers, i.e., tsunami-induced seawater intrusion (TSWI), which can threaten the quality of groundwater resources. Numerical modeling is a useful tool and has been used in previous studies to understand TSWI processes based on the major tsunami disaster in 2004 and 2011. However, little work has been done to predict TSWI under future tsunami scenarios, especially in the vicinity of seismically active zones like Japan. Furthermore, the interpretations of the simulation results of TSWI can be problematic due to a series of model uncertainties with respect to tsunami inundation scenarios, site specific aquifer properties, anthropogenic activities, and so on. Therefore, this study tends to numerically simulate TSWI in coastal aquifers under future tsunami scenarios and examine the impacts of model uncertainties on simulation results. For this purpose, both a conceptual problem and a field-based case were studied by numerical modeling using the code FEFLOW, which solves variable-density flow and mass transport in unsaturated-saturated porous media.

First, a conceptual problem was designed, in which saltwater was injected vertically from the top into a 2-D vertical cross-section of an unconfined aquifer under horizontal groundwater flow conditions. In total, 158 numerical simulation cases were designed with various configurations of horizontal groundwater flow, solute injection, aquifer properties, and dispersivity. Three end-member flow regimes were identified that were dominated by the horizontal hydraulically-driven flow, the vertical hydraulically-driven flow, and the vertical density-driven flow, respectively. The flow regimes and parameter sensitivity were explained by a system integrating three dimensionless numbers, the convective ratios M_x and M_z, and the Rayleigh number Ra_d. The understanding based on the simulations of this conceptual problem provided a basic reference for interpretation of saltwater migration in TSWI problems.

Next, the numerical approach was applied to predict TSWI in a real site. The Niijima Island, Japan, was selected to be the case, because groundwater is the only source for freshwater in the island but facing high risks of TSWI under the future Nankai earthquake scenarios. Both 2-D and 3-D numerical models of the groundwater system in the Niijima Island were developed and calibrated. A series of simulation cases were designed for studying the impacts of model uncertainties including tsunami inundation conditions, aquifer properties, rainfall recharge settings, and groundwater abstraction activities. The simulated tsunami inundation of 15 m a.m.s.l. (above mean sea-level) would cause seawater, with a volume scale of 10^6 m^3, to infiltrate into subsurface within several tens of minutes, and groundwater salinization would persist for about eight years. An extreme tsunami of 20 m a.m.s.l. could cause a broader seawater flooding zone, and as a result, TSWI may deteriorate the groundwater quality even in no-inundated zones, which would require a period of more than 18 years to be recovered by the natural rainfall recharge. The field settings including unsaturated zone properties, groundwater flow path and travel time, and bedrock surface topography, had important influences on simulation results, and they can provide useful information with respect to the estimation of the total amount of seawater infiltration, direction of contaminant migration, and total time for recovery of polluted aquifers. Simulation results indicated that some groundwater in the southeastern part of the island would be survived from seawater intrusion, and this survived portion of groundwater resource had the potential to provide post-disaster water supply in an equivalent amount of the pre-tsunami level (3.7×10^5 m^3/year), and at the same time, did not worsen the recovery processes.

This study is expected to provide a more comprehensive understanding of TSWI processes and a better strategy to perform numerical modeling approaches to solve coastal hydrological processes.