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Prediction of National-Scale Groundwater Level Change Using Deep Learning Approaches to Verify Long-Term Stability of Geological Disposal System

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1. Introduction

Disposal of high-level radioactive waste at a deep geological repository has been considered as the only mean to isolate radioactive waste from ecosystem. In order to keep the deep geological repository successful, maintaining reducing conditions in an underground deep environment is critical to suppress the mobility of radionuclides, including uranium. In order to verify them, it is important to evaluate the redox conditions and behavior mechanisms of uranium using available data from the previous researches. In this study, groundwater level is considered as a major factor that not only provides information about the direction and velocity of groundwater flow, but also affects the redox conditions.

This study attempted to analyze patterns of the past groundwater level fluctuations and predict future changes on a national scale and on a long-term time scale. In particular, we developed a spatio-temporal machine learning model utilizing the past data of precipitation (30 years) and groundwater level (16 years) to predict surface change patterns over the next 100 years by applying various climate change scenarios. It was intended to divide South Korea spatially to indicate the resulting changes in groundwater levels in each zone.

2. Methods and Results

As spatio-temporal predictive models require time-series of raster data types for inputs, South Korea was divided into 22 zones with a same interval of 75 km. In the raster grid, precipitation and groundwater level data were collected, and they were used for developing a deep learning model which predicts future groundwater level in South Korea, after the pre-processing.

2.1 Standardized precipitation index and standardized groundwater level index

The standardized precipitation index (SPI) is an indicator of drought and is calculated based on monthly precipitation data [1]. In this study, precipitation data from 1992 to 2021 were collected at 350 meteorological stations provided by the Korea Meteorological Administration (KMA). Using 1-month precipitation, SPI01 is calculated, and several types of SPIs can be calculated depending on the number of cumulative months. A low cumulative SPI indicates a short-term drought, a high cumulative SPI indicates a long-term drought, and SPI1-12 were utilized in this study.

The standardized groundwater level index (SGI) is calculated by standardizing the average monthly groundwater level [2]. In this study, groundwater levels at 229 stations observed during 16 years (2006-2021) were collected by the National Groundwater Information Center. The SGIs in the same zones averaged each other, resulting in a time series of raster data consisting of 22 zones of SGIs over 192 months.

2.2 Convolutional long short-term memory network

Convolutional long short-term memory network (ConvLSTM) is a deep learning model that predicts spatial distribution extended from long short-term memory networks (LSTM) specialized in time series prediction [3]. In the LSTM operation process, the product operation can be replaced by the convolution operation to receive the time series of the raster as input and output the raster result at the following points. In this study, ConvLSTM models were developed to predict the SGI of the raster type at future time points from the raster data of SPI01-SPI12 at t-11 to t (12 months). 15 different ConvLSTM models were generated by combining various parameters in ConvLSTM, the number of ConvLSTM layers (1, 2, 3) and the number of filters (30, 35, 40, 45, 50). 15 models were trained and validated using identical data, and an ensemble method made a final prediction result from 15 different model outputs.

2.3 Model performance

Fifteen different ConvLSTM models showed RMSE errors in the range of 0.1310–0.2304, when the mean was 0.1804 for train data. For validation data, mean of RMSE was 0.3293, and their range was from 0.3110 to 0.3408. An ensemble model that was made by averaging the results of 15 ConvLSTM models showed improved performance. RMSE of the ensemble model was 0.1298 for the train data, and 0.2822 for the validation data. The lower error of the ensemble model compared to the individual ConvLSTM models indicates that the mean of multiple predictive models converges to real SGI values.

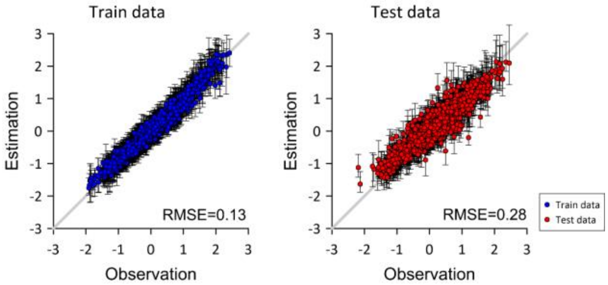

Fig. 1. Model performances for train data (blue) and validation data (red). Dots are results of ensemble model, and the performances of the individual ConvLSTM models are illustrated by error range.

2.4 Future prediction according to SSP scenarios

This study applied three different SSP scenarios (SSP1-2.6, SSP2-4.5, SSP5-8.5) for future prediction of SGI in South Korea. The ensemble model of ConvLSTM predicted future SGIs in 22 zones depending on climate change by 2100. Because the precipitation was different for each scenario, predicted SGIs showed different patterns as time goes on.

To compare the SGIs in the future according to SSP scenarios with the past SGI distribution, histogram of the SGI for every 20 years were analyzed. The results showed that predicted SGI according to SSP126 are similar to the past SGI distribution. However, SGI predictions according to SSP245 and SSP585 represented a clear rise in SGI after 2040. The ratio of negative SGIs became smaller and that of positive SGIs coutinued to increase over the period.

3. Conclusions

A deep learning approach, convolutional long short-term memory network contributed to predict groundwater level on a national scale. The groundwater level can affect redox environments as well as groundwater flow system. Thus, it is one of main factor to discover behavior of uranium in subsurface system. The attempt to predict changes in spatio-temporal groundwater level according to climate change in this study is useful for tracking the groundwater flow system and behavior of radionuclides with respect to redox condition.

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