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Uncertainty assessment of future high and low flow projections according to climate downscaling and hydrological models

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Abstract

The quantitative assessment of change in water availability and appropriate water resources management are needed for corresponding adaptation. However, there are large uncertainties in climate change impact assessment on water resources. In this sense, the aims of this study are to suggest the uncertainty assessment method for climate change impact assessment and to investigate the uncertainty characteristics for high and low flow between downscaling methods and hydrological models. The 5 RCMs (HadGEM3-RA, RegCM4, MM5, WRF, and RSM), 5 statistical post-processing methods (SPP), and 2 hydrological models (HYM) were applied on the Chungju dam basin, Korea. The results of uncertainty analysis showed that RCM has the largest sources of uncertainty in 1-day maximum dam inflow (about 40.7%), while HYM has the largest sources of uncertainty in 30-days minimum dam inflow (about 41.5%). In other words, high flow was mainly effected by RCM and low flow by HYM. The proposed methodology in this study can be used to quantify the uncertainties caused by RCM, SPP, and HYM.

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Keywords: *Climate change; Uncertainty analysis; Hydrological model; Water Resources, Variance analysis*

1. Introduction

Recently, it is expected that water resources will be changed due to global warming. IPCC AR5 (The fifth Assessment Report of Intergovernmental Panel on Climate Change) presented that global mean temperature and sea level were expected to rise about 3.7℃ and 63mm for the end of the century (2081~2100). Also, water related risks will be increase, and then the water disaster damage will be exacerbated due to high population and water resources variation in Asia region [1]. Therefore, it is necessary to consider the climate change impact assessment on water resource management plan. In addition, climate change impact assessment results should have high reliability. However, climate change assessment results have uncertainty because of the several sources such as greenhouse gas emission scenario, global climate simulation, regional climate simulation, and hydrological modeling [2]. There are some limitations which is difference of future projection according to the methodology because the various downscaling method and hydrological model exist. For this reason, development of methodology to evaluate the uncertainties quantitatively is required.

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Recently, several climate change and uncertainty analysis researches were done. [3] assessed the changes in flood frequency for future period in England, and suggested that GCM is dominant uncertainty source. [4] evaluated the uncertainty of high and low flow according to selection of GCM and scenario. [5] assessed the stream flows using 2 scenarios, 6 GCM, 4 downscaling methods, and 3 hydrological models. Their results showed that the uncertainty of GCM is higher than the other steps. These previous studies were focused on range estimation of projection results using ensemble models and uncertainty analysis was done by using simple comparison of result range for each step. None of these studies assess the uncertainty caused by downscaling method and hydrological model. However, these two sources are considered main uncertainty sources and requested to consider in climate change impact studies.

The present study is aimed to compare the uncertainty caused by downscaling methods and hydrological models in high and low flow condition of future dam inflow of Chungju dam basin. The proposed method can be applied to quantify uncertainty sources for climate change impact assessment.

2. Methodology

2.1. Climate change scenario

The results of the CORDEX (COordinated Regional climate Downscaling EXperiment) - East Asia project were used in this study. The major aims of the CORDEX are to provide a coordinated model evaluation framework, a climate projection framework, and an interface to the applicants of the climate simulations in climate change impact, adaptation, and mitigation studies. CORDEX-East Asia is the East-Asian branch of the CORDEX and will produce ensemble climate simulations based on multiple dynamical downscaling models forced by multiple global climate models. Five RCMs (HadGEM3-RA, RegCM4, SNU-MM5, SNU-WRF, and YSU-RSM) results are provided in the CORDEX-East Asia experiment. The experiments are conducted for the current climate and future climate projections. The current climate simulation is driven from the historical run of the Atmosphere-Ocean coupled Hadley center Global Environmental Model version 2 (HadGEM2-AO) simulation of the National Institute of Meteorological Research (NIMR) [6]. For the future climate simulations, two different boundary conditions from the Representative Concentration Pathways (RCP) 4.5 and 8.5 scenarios of HadGEM2-AO are used. The detailed information refer to the CORDEX–East Asia webpage (https://cordex-ea.climate.go.kr/).

There are bias in the climate simulation data produced by climate models due to limitation of model structure and parameterization. Therefore, the statistical post-processing method is necessary to use climate simulation data. The linear scaling method (LS), Variance scaling method (VS), Quantile mapping method (QM), Change factor method (CF), and Step-Wise scaling method (SWS) are used in this study. The LS method is the most commonly used for climate change impact studies. This method uses differences of monthly average between observation and scenario. VS method is the method using differences of monthly mean and standard deviation between observation and scenario. QM is a method to correct the distribution function of simulated climate values corresponding to the observed distribution function of daily climate data. CF method is to determine monthly change ratio between present and future climate simulation, and then multiply the ratio to the past historical climate data. The SWS method is divided by 3 categories (extreme event, dry event and the others). The extreme events, wet-dry days and the others are corrected by using regression method, quantile mapping method, mean and variance scaling method [7].

2.2. Hydrological model

A semi-distributed hydrological model SWAT (Soil and Water Assessment Tool) and distributed model VIC model were used for runoff analysis. SWAT model was developed by Agricultural Research Service in USDA, and has been widely applied to predict the effects of climate and vegetative changes, groundwater withdrawals and reservoir management [8]. The VIC model developed by Dr. Dennis Lettenmaier research group in University of Washington is used for the analysis of water availability over Asian Monsoon region [9]. It shares several basic features with the other land surface models that are commonly coupled to global circulation models. The key characteristics of the grid-based VIC are the representation of vegetation heterogeneity, multiple soil layers with variable infiltration, and non-linear base flow. The land surface is modeled as a grid of large (>1 km), flat, uniform cells. Sub-grid heterogeneity is handled via statistical distributions. Inputs are time series of daily or sub-daily meteorological drivers. Land-atmosphere fluxes, and the water and energy balances at the land surface are simulated at a daily or sub-daily time step.

2.3. Uncertainty analysis

There are several uncertainty assessment methods such as Bayesian Model Average [10], GLUE [11], Paired t-test [5], Monte-Carlo simulation [12], and Variance analysis [13]. This study focused on quantification of the uncertainty contribution for each step, and therefore used the variance analysis. For this study, the uncertainty sources consist with regional climate model (RCM), statistical post-processing (SPP), and hydrological model (HYM). The total uncertainty defined in this study is the variance of the changes (U_{FUT}) in future dam inflow (Q_{FUT}) relative to the historical dam inflow (Q_{CTL}) (Eq. 1).