A Grid-based Modeling for Assessing Climate Change Impact on Watershed Hydrology

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ABSTRACT

This study is to develop a grid-based hydrologic model for evaluating future climate change impact on watershed hydrology. The model is a typical distributed model, which divides the watershed into regular cell elements and calculates the daily water balance of each cell by constructing 3 vertical layers of surface, subsurface, and groundwater flow respectively. For a 930.4 km^2 Yongdam Dam watershed located in the middle of South Korea, the model with 1.0 km spatial resolution was calibrated and validated using 8 years (2002-2009) daily streamflow data at 3 locations with Nash-Sutcliffe model efficiency of 0.61~0.82. For the future climate change scenario, the HadGEM3-RA RCP 4.5 and 8.5 scenarios were prepared for 2040s (2020-2059) and 2080s (2060-2099) with 12.5 km spatial resolution. The future hydrologic components viz. evapotranspiration, soil water contents, surface runoff and streamflow were suggested as both integrated and spatially distributed results.

Keywords: Grid-based, Modeling, Climate change, Watershed, Hydrology

1. Introduction

A grid-based distributed hydrologic modeling can give us valuable information during the hydrological processes with both temporal and spatial aspects. We can look at the happenings of water cycle and extract some information at the level of a given cell dimension.

When we try to assess the climate change impact on watershed hydrology, it is necessary to trace the responses of hydrologic behavior where they were occurred and how much were changed. This can help the establishment of water resources conservation and adaptation planning at the watershed scale.

Thus, this study describes the development of a grid-based continuous hydrologic model for climate change assessment. Ultimately, the model will be extended to apply for 99,000 km^2 of South Korea.

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2. Study Area and Data

For model development, Yongdamdam watershed (930 km^2) which is located within N35°35´~36°00´ and E127°20´~127°45´ was adopted (Figure 1). Daily weather data for Penman-Monteith evapotranspiration were obtained from Korea Meteorological Administration. For model calibration and validation, the daily streamflow data were obtained from WAter Management Information System (WAMIS, http://www.wamis.go.kr). The data of elevation, soil type, land use, and the temporal data were prepared as a 1 km resolution grid with 46 rows and 55 columns.
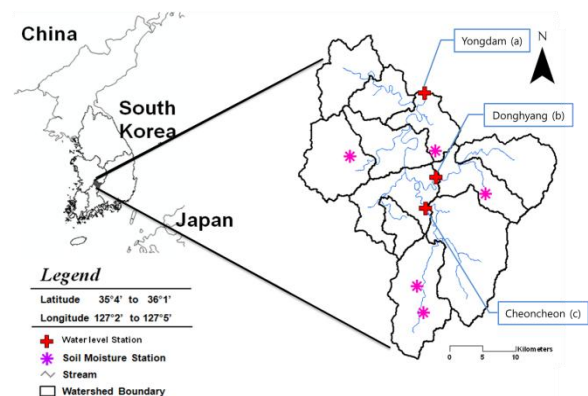

FIGURE 1. Location of the Yongdamdam watershed and the water level stations.

3. Model Description

The model divides the watershed into rectangular cells, and the cell profile is divided into three layers: surface layer, subsurface unsaturated and saturated layers. The model performs the soil water routing in a daily base for each grid element. When it rains, the surface runoff is simulated by the available storage of soil moisture contents. Evapotranspiration is calculated by Penman-Monteith method considering Leaf Area Index (LAI) of vegetation canopy, and the percolation rate to deep groundwater layer is controlled depending on the soil field capacity and the saturated hydraulic conductivity. The model introduced six important parameters viz. surface lag coefficient, soil percolation ratio, lateral flow recession curve slope, lateral flow basin lag time, base flow recession curve slope, and base flow basin lag time for model calibration.
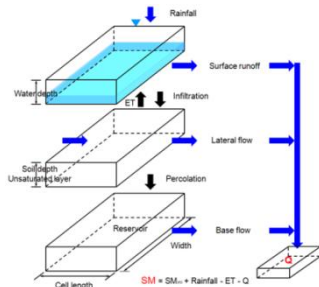

FIGURE 2. Schematic representation of the flow system (Kim et al., 2005).

4. Model Calibration and Validation

The model was calibrated for 5 years (2002-2006) and validated for 3 years (2007-2009) for daily streamflow data at 3 locations (Yongdam, Donghyang, and Cheoncheon) respectively.

Table 1 shows the summary of model calibration and validation.

5. Model Application for Climate Change Impact Assessment

Table 2 shows the future temperature and precipitation scenarios and the projected 2040s and 2080s model results of evapotranspiration and streamflow, and figure 3 shows the spatial results of future seasonal surface runoff based on the baseline period (2002-2009).

6. Summary and Conclusion

This study developed a grid-based hydrologic model for the purpose of assessing future climate change impact on watershed hydrology. For a 930.4 km^2 watershed, the model was calibrated and validated using 8 years daily streamflow data at 3 locations with Nash-Sutcliffe model efficiency of 0.61~0.82. For model application, the future climate data of HadGEM3-RA RCP 4.5 and 8.5 scenarios were prepared for 2040s (2020-2059) and 2080s (2060-2099) and the future hydrologic components were generated both integrated and spatially distributed results based on baseline period of 2002-2009.

TABLE 1. Statistical summary of the model calibration and validation results

Gauging station		Yongdam (A)	Cheoncheon (B)	Donghyang (C)
Rainfall (mm/yr)		1478.7	1291.6	1462.6
Streamflow (mm/yr)	Observed	878.8 (59.4%)	845.7 (57.8%)	945.8 (73.2%)
	Simulated	906.9 (61.3%)	880.0 (60.2%)	740.7 (57.3%)
Nash-Sutcliffe model efficiency	Calibration (2002-2006)	0.84	0.65	0.66
	Validation (2007-2009)	0.78	0.60	0.53

TABLE 2. Summary of future predicted hydrologic components for HadGEM5-RA RCP 4.5 and 8.5 scenarios in 2040s and 2080s

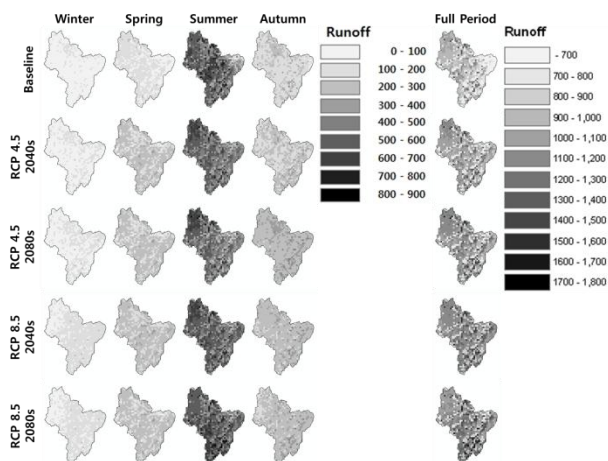| Components	Baseline (2002-2009)	RCP 4.5		RCP 8.5	
		2040s	2080s	2040s	2080s
Temperature (℃)	6.24	7.09 (+0.85)	8.06 (+1.82)	7.79 (+1.55)	10.73 (+4.49)
Precipitation (mm)	1462.9	1550.4 (+6.0%)	1633.4 (+11.7%)	1660.2 (+13.5%)	1736.4 (+18.7%)
Evapotranspiration (mm)	520.8	462.7 (-11.2%)	492.4 (-5.5%)	455.6 (-12.5%)	533.9 (+2.5%)
Streamflow (mm)	892.4	1004.2 (+12.5%)	1057.8 (+18.5%)	1111.2 (+24.5%)	1116.4 (+25.1%)

FIGURE 3. The 2040s and 2080s surface runoff based on baseline (2002-2009)

Acknowledgments

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