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Article

Prospect of Discharge at Daecheong and Yongdam Dam Watershed under Future Greenhouse Gas Scenarios using SWAT Model

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Abstract. In this study, the future expected discharges is analyzed at Daecheong and Yongdam Dam Watershed under Future Greenhouse Gas Scenarios based on RCM with 1 km spatial resolutions from Korea Meteorological Agency (KMA). HadGEM2-AO, which is the climate change prediction model that KMA recently introduced is used for this study. Geum river watershed area is 9,914.013 km^2 and there are two dams, one of dam is Daecheong Dam completed in 1980, the other dam is Yongdam Dam completed in 2001. The runoff is simulated using the ArcSWAT model from 1988 to 2010. The simulation is in good agreement with measured data at the Yongdam Dam and Daecheong Dam showing R^2 of 92.25% and 95.40% respectively. Using the average discharge from 2001 to 2010 as a baseline, the simulated annual average discharge increased by approximately 47.76% and 36.52% under the RCP4.5 scenario and RCP8.5 scenario respectively for the period from 2011 to 2100.

Keywords: SWAT, discharge, climate change, RCP scenario, HadGEM2-AO.

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1. Introduction

As the global warming causes extreme weather by climate change, also increases the meteorological disaster such as typhoon, flood and severe drought. It was found that the average temperature is expected to rise from 1℃ to 6℃ in the next century. Korea Meteorological Administration (KMA) recently studies that temperature and precipitation will increase 4.8℃ and 6% respectively at the end of the 21st century (2070-2099) rather than those of the past 30years (1971-2000) [1]. In particular, Korea has geomorphologically mountainous terrain more than 70% of the country. Flood happens frequently because climatologically average annual rainfall of more than 60% occurs from June to September. As runoff pattern changes by increasing temperature and precipitation, extreme flood and drought have occurred and runoff has changed. Therefore, it is necessary to analyze changes in the hydrological environment and to quantize flow units that we resolve a hydrological cycle change and stable water supply.

In this paper, we will look at the runoff change of the dam basin under climate change through quantitative evaluation for the period from 2011 to 2100. HadGEM2-AO model was used as an optimized GCM model on the Republic of Korea. And HadGEM3-RA model based on RCP scenario with 1 km resolution that exploits dynamic downscaling technique was used for producing future rainfall data on a regional scale. The SWAT model, a semi-distributed hydrological model, analyzes the watershed runoff by inputting RCP scenarios on rainfall and temperature data. This approach is applied to the Yongdam Dam and Daecheong Dam watershed. Hyun et al. (2012) [2] says that result of HadGEM2-AO is superior to that of CMIP3 which is AR4. And it has better performance than reanalysis data of NCEP / NCAR. Therefore, evaluation using HadGEM2-AO under new greenhouse scenario is more reliable for responding against climate crisis than using existing climate change model.

2. Study Area

Geum river basin which includes Yongdam and Daecheong Dam Watershed, the subject area of this study, two multi-purpose Dams are installed to prevent flood and Geum river Estuary Dike is installed at the mouth of Geum river. It is located in the midwest of Republic of Korea. This river is situated in north latitude 35˚35´-37˚05´, east longitude 126˚41´-128˚25´. It is the third largest river following Han River, the Nakdong River. Geum river watershed consists of the subbasin of fourteen, drainage area is 9,914.013 km^2, basin average slope is 16.7%, basin length is 388.45 km, basin circumference is 737.89 km, effective basin width is 25.52 km, basin average elevation is EL.85.31 m, the average annual temperature is 11.5℃, amount of evaporation each of weather station is 1,070-1,292 mm [3].

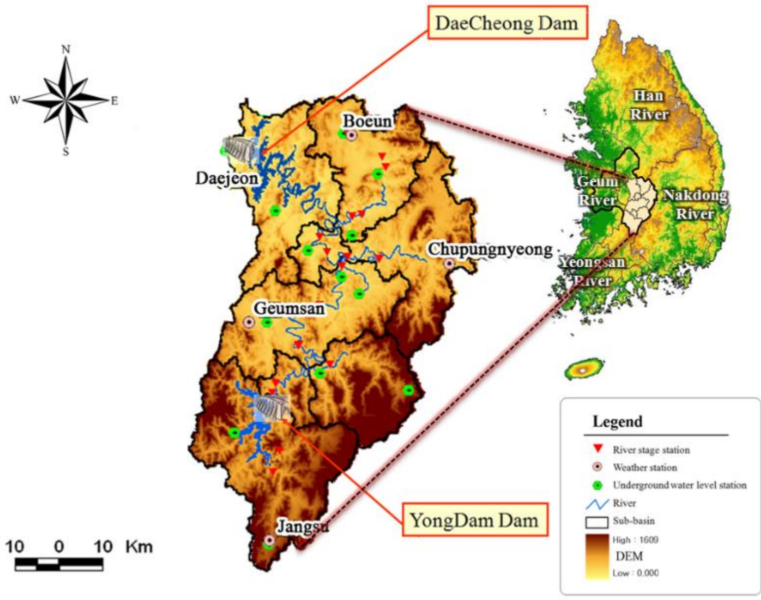

Fig. 1. Location of Daecheong Dam (up) and Yongdam Dam (down).

There are two dams, one of which is Yongdam Dam 329km upstream from the Geum River Estuary. The other dam is Daecheong Dam, 150km upstream from the Geum River Estuary. Area of the Yongdam Dam watershed is 930 km^2, area of Daecheong Dam excepting Yongdam Dam watershed is 3,204 km^2. Figure 1 shows watershed division of Daecheong Dam watershed including Yongdam Dam and location of each weather station.

3. Climate Data

3.1. Downscaling of Climate data

The GCM of this study is HadGEM2-AO, installed on the supercomputer of the Korea Meteorological Administration and released data of downscaling by KMA (Korea Meteorogical Administration). KMA applied HadGEM2-AO which is climate change model of Hadley Centre in United Kingdom to set next-generation global forecast system and it consists of atmosphere-ocean-sea ice-hydrological-aerosol coupled model [1]. Figure 2 shows the process of calculating the climate change scenario. The data from Global Climate Model (HadGEM2-AO) are formulated with initial condition regional climate model (HadGEM3-RA). Then dynamical downscaling is done with obtained data by 12.5 km resolution. 1 km resolution data in the South Korea are yielded by using detailed data and PRIDE which is spatial statistical downscaling model. In order to quantitatively predict the runoff, we used the high resolution 1km RCP scenario data (www.climate.go.kr).

3.2. Climate Change Scenario

RCP scenario expresses the "Representative" which social - economic scenario is possible to have several meaning about single representative in radiative forcing. In addition scenario expresses the "Pathways" to emphasize the variation with time of greenhouse gas emission scenarios [4]. Additional Downscaling is not included in the study. Because, RCP scenario applies high resolution treated with dynamical downscaling by 12.5 km resolution and PRIDE which is spatial statistical downscaling model (Table 1).

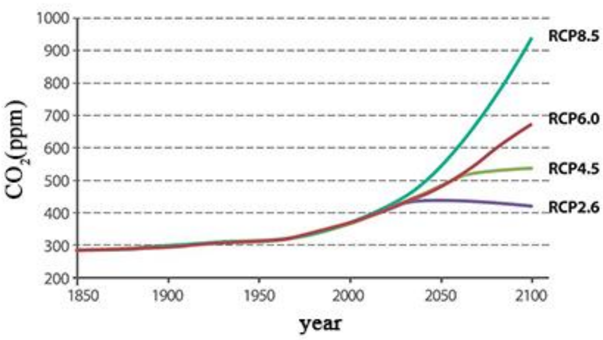

Fig. 2. Changes in CO_2 concentrations of the RCP scenario [4].

Table 1. Types of Greenhouse Gas Scenarios [4].

Category	CO_2(ppm)	Meaning
2.6	421	The case that earth can recover the impact of human activities itself
4.5	538	The case that Greenhouse gas reduction policy is substantially realized
6.0	670	The case that Greenhouse gas reduction policy is slightly realized
8.5	936	The case that Greenhouse gas exposes without reduction

4. Model Description

SWAT is abbreviation of Soil and Water Assessment Tool and is a watershed model developed by Jeff Arnold of the USDA Agricultural Research Service (ARS). The SWAT model is a hydrological model and can be simulated at daily / daily time intervals [5].

$$SW_t = SW_o + \sum_{t=0}^{t}(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \tag{1}$$

Where SW_t is the final soil water content (mm), SW_o is the initial soil water content on day i(mm), t is the time(days), R_{day} is the amount of precipitation on day i(mm), Q_{surf} is the amount of surface runoff on day i(mm), E_a is the amount of evapotranspiration on day i(mm), W_{seep} is the amount of water into the deep aquifer on day i(mm), and Q_{gw} is the amount of return flow on day i(mm) [5].

It is a semi - distributed long - term rainfall runoff model. It is composed of hydrology, soil erosion and sedimentation, nutrients, and land management. In this study, rainfall runoff simulation was the main focus. SWAT model inputs are elevation Digital Elevation Model (DEM), landuse/cover, soil, weather station, daily rainfall, maximum and minimum temperature, radiation, wind speed, relative humidity and reservoir Information. The watershed delineation is sub-divided into subbasins that are calculated for each hydrologic response units (HRUs) and routed to obtain the total runoff of the watershed. The HRUs are homogenous units that possess unique landuse/cover and soil attributes. The surface runoff is calculated using the SCS curve number method. Runoff was predicted separately for each hydrologic response unit (HRU) [6].

5. Simulation SWAT

5.1. Input Data

To apply ArcSWAT model on Daecheong and Yongdam Dam watershed, we divide watershed by input of DEM and create HRU by using Landuse and Soil. Weather data which are basic data for computing discharge were received from KMA and WAMIS. It includes rainfall, highest and lowest temperature, solar radiation, relative humidity, wind.

5.2. Calibration and Validation of SWAT

There are several methods to evaluate the simulation result of rainfall runoff model. In this study compatibility of model is evaluated by using R^2 (Pearson's coefficient of determination, Legates and McCabe, 1999) [7], EI (model efficiency coefficient, Nash and Sutcliffe, 1970) [8], VER and QER. Each equation is as follows:

$$R^2 = \left(\frac{\sum_{t=1}^{n}(O_i - \overline{O})(P_i - \overline{P})}{\sqrt{\sum_{t=1}^{n}(O_i - \overline{O})^2}\sqrt{\sum_{t=1}^{n}(P_i - \overline{P})^2}} \right)^2 \tag{2}$$

$$EI = 1 - \left(\frac{\sum_{t=1}^{n}(O_i - P_i)^2}{\sum_{t=1}^{n}(O_i - \overline{O})^2} \right) \tag{3}$$

$$VER = \left| \frac{\sum(Q_{obs} - Q_{cal})}{\sum Q_{obs}} \right| \times 100 < 15 \tag{4}$$

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$$QER = \left| \frac{Q_{pobs} - Q_{pcal}}{Q_{pobs}} \right| \times 100 < 15 \tag{5}$$

where P_i and O_i are simulated and observed data, respectively, on each time step i(day or month), P and O are mean values for simulated and observed data during the examination period, n is number of observation/simulation data for comparison(Pearson's coefficient of determination, Legates and McCabe, 1999) [7].

Where Q_{obs} is the observed discharge (m^3/sec), Q_{cal} is the calculated discharge (m^3/sec), Q_{pobs} is the observed peak discharge (m^3/sec), Q_{pcal} is the calculated peak discharge (m^3/sec). Van Liew et al. (2007) [9] say that CN2, ESCO and SOL_AWC are simulation of surface flow, GW_REVAP, REVAPMIN, GWQMN, GW-DELAY, ALPHA_BF and RCHRG_DP are simulation of subsurface flow, SURLAG, CH_K2, TIMP, SFTMP, SMTMP, SMFMX and SMFMN are simulation of groundwater flow.

In this study, CN2, ESCO, the SOL_AWC are selected as parameter with reference to journal about simulating the flow of surface water (Table 2). Range of parameters that can reduce the runoff is selected because simulation was higher than observed. Then, specific number of parameters are adjusted by the method of trial and error. In order to set the optimum correction period, this is calibrated in the trial period (2004-2006) and validated in the trial period (2007-2009).

Table 3 shows the results of the reliability assessment of the SWAT using R^2, EI, VER and QER. As a result of comparing the simulated discharge with observed discharge, both EI and R^2 were higher than 80% that we found that there is a correlation between simulation data and observed data. In addition average VER and QER are less than 20%, which can be applied to actual work (Figs. 3-4).

Table 2. Calibrated parameters values.

Parameters	Definition	Input File	Value
CN2	SCS runoff curve number	.MGT	▽2
ESCO	Soil evaporation compensation coefficient	.HRU	0.5
SOL_AWC	Available water capacity of the soil layer	.SOL	▽0.1

Table 3. Assessment of applicability for SWAT model.

Division	R^2 (%)	EI(%)	VER(%)	QER(%)	Total Discharge Error(%)
Yongdam	92.25	88.68	15.37	11.29	9.90
Daecheong	95.40	91.50	17.88	4.38	15.7
Average	93.83	90.09	16.63	7.84	12.80

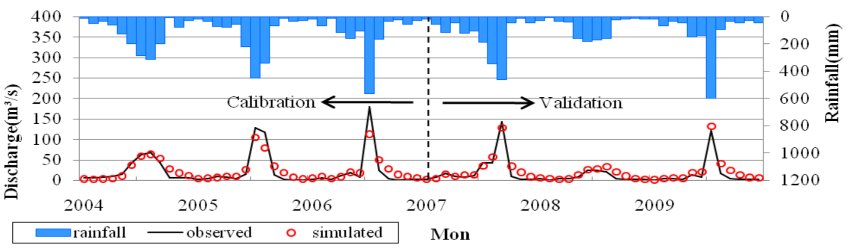

Fig. 3. Runoff analysis result at Yongdam Dam Point.

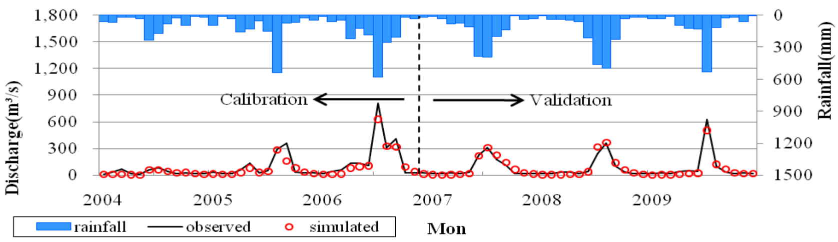

Fig. 4. Runoff analysis result at Daecheong Dam Point.

5.3. Input Outlook of Future Discharge

Scenario was provided two of the four RCP greenhouse gas scenarios which it provides climate information portal. RCP8 and RCP4.5 scenario were entered into the SWAT model. In order to compare a discharge, it set a duration which the observed runoff set over the past 10 years (2001-2010) and future runoff set over the future 90 years (2011-2100). Future duration divides a 21st century in 3 segments which is 2020's (2011-2040), 2050's (2041-2070) and 2080's (2071-2100). As a result of the analysis, annual average runoff will prospect under the RCP4.5 and RCP8.5 showing increase of 92.25% and 95.40% respectively compared with past (Table4, Figs. 5-6).

As a result of increasing rate of annual average rainfall, RCP4.5 scenarios showed the biggest increase in 2080's and it in totality increased as time goes by. On the other hand RCP8.5 scenario showed the biggest increase in 2050's and increasingly decreased since the 21st century. The runoff has decreased in the late 21st century. Because potential evapotranspiration has increased according to the decrease of rainfall and increase of temperature under the RCP8.5 scenario [10]. In addition, runoff variously will be changed depend on condition of landuse and various terrain factor.

As shown in Figs. 7-8, in fall and winter result of the analysis of the seasonal, runoff has dramatically increased on both scenario in the Yongdam and Daecheong Dam watershed. In the fall runoff will prospect under the RCP4.5, RCP8.5 scenario showing increase of 77.62%-143.15% and 49.61%-141.57% respectively. In the winter, runoff will prospect under the RCP4.5, RCP8.5 scenario showing increase of 34.29%-122.85% and 34.75%-155.74% respectively. Also, in the summer runoff will prospect under the RCP4.5, RCP8.5 scenario showing increase of 11.88%-51.73% and (–)12.18%-37.49% respectively. Increase rate of RCP4.5 is larger than RCP8.5. This is expected to change the pattern in fall and winter, rainfall that has been seen only in summer rainfall ever will be sees many more.

Table 4. Future rainfall and discharge.

Scenario		Rainfall(mm) / Discharge(m³/s)			
		2001 - 2010(year)	**2011 - 2040(year)**	**2041 - 2070(year)**	**2071 - 2100(year)**
RCP 4.5	Yongdam	1,507.68 / 302.21	1,755.52 / 421.80	1,848.06 / 448.48	1,914.85 / 464.24
	Daecheong	1,357.07 / 952.63	1,635.20 / 1,365.28	1,664.32 / 1,379.88	1,785.59 / 1,493.57
RCP 8.5	Yongdam	1,507.68 / 302.21	1,664.58 / 387.03	1,882.35 / 454.47	1,757.38 / 398.24
	Daecheong	1,357.07 / 952.63	1,603.10 / 1,221.98	1,762.35 / 1,448.80	1,741.38 / 1,224.30

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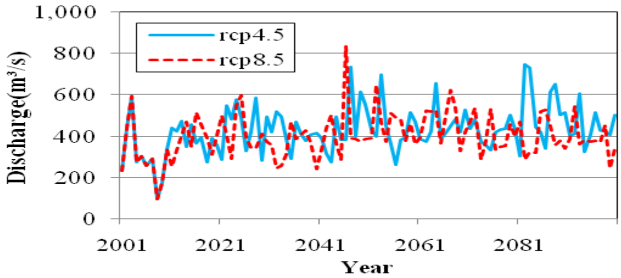


Fig. 5. Prospect of future discharge in Yongdam.

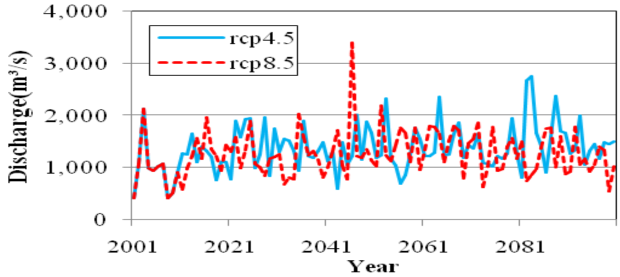
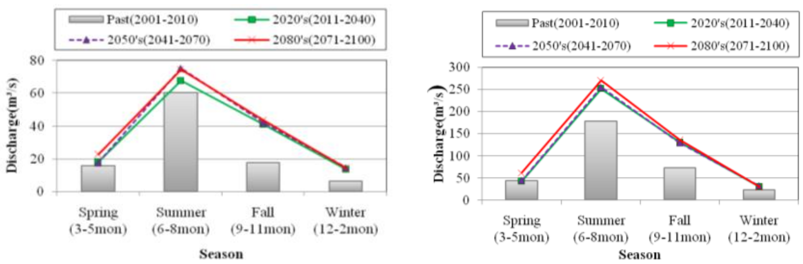
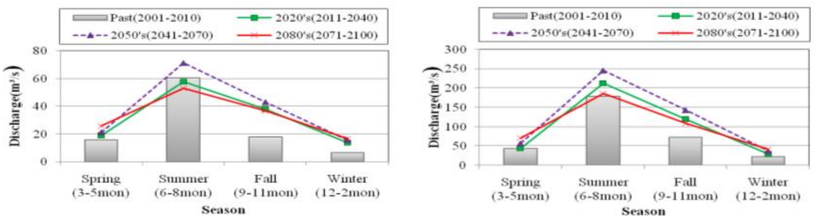


Fig. 6. Prospect of future discharge in Daecheong.



(a) Yongdam (b) Daecheong

Fig. 7. Comparison of different ages under RCP4.5 runoff scenario.



(a) Yongdam (b) Daecheong

Fig. 8. Comparison of different ages under RCP8.5 runoff scenario.

6. Conclusions

In this paper, we calculated runoff on Dam watershed under the new greenhouse gas scenarios using SWAT which is a rainfall-runoff model. Scenario data ware extracted to analyze the temperature and rainfall pattern over the next 90 years by weather stations on Dam.

1) The new greenhouse gas emission scenarios which is global climate change scenario with 135 km resolution was yielded by HadGEM2-AO which is global atmospheric-oceanic coupled model and RCP scenario. Then, Regional scenario in Korea with 12.5 km resolution was yielded with HadGEM3-RA which is regional climate model and previously yielded scenario. Then, 1 km high resolution detailed climate change scenarios in South Korea was yielded by statistical elaboration techniques to regional scenario.

2) The runoff of Yongdam Dam and Daecheong Dam watershed from 1988 to 2010 was simulated by the ArcSWAT. The simulation was in good agreement with measured data at the Yongdam Dam and Daecheong Dam with R^2 of 92% and 95% respectively.

3) The discharge increases up to 47.76% under RCP4.5 scenario and 36.52% under the RCP8.5 scenario. The seasonal patterns of discharges would be change compared with the present since the simulated discharge of fall and winter was increased.

The result of the study is performed based on the rainfall and temperature data that simulated under future greenhouse gas scenarios. Therefore, the reliability of the prediction is uncertain because it depends on the accuracy of physical processes in GCM model and climate change scenario. To reduce the uncertainty, the KMA performs research about the finding through the ensemble of various meteorological model data. Research on weather is necessary. In addition sustainable study that can minimize uncertainty by using quantitative evaluation method considering uncertainty is also necessary.

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