Assessment of Future Climate Change Impact on Groundwater Behavior of Geum River Basin in South Korea Using SWAT

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Groundwater level fluctuation distribution

Point Data
166 Station data from KMA

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Introduction

• According to the IPCC Fourth Report (2007), the most vulnerable part of future climate change was selected as the change in water availability due to the time-space change of the precipitation pattern.
• The IPCC Fifth Report (2014) proposes water diversification and integrated water management, especially in Asia, such as water recycling.
• If the flow rate is slow and continuous, such as groundwater changes, the effects of surface climate change can not be readily perceived. But, If fluctuations due to surface changes begin to be observed in the groundwater environment, the effects are much longer than the surface. Therefore, an analysis of groundwater behavior is required for efficient management of water resources following future climate changes.
• The purpose of this study is to evaluate the groundwater level behavior of Geum river basin (9,645.5 km²) under future climate change scenario projection periods using SWAT.
Flowchart of this study

1. Model Input

<table>
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<tr>
<th>Groundwater use data</th>
<th>Multipurpose Dam Data</th>
<th>Observed Data</th>
<th>GIS Data</th>
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<td>▪ Resources from NGIC</td>
<td>▪ 2 multipurpose water supply dams (1982-2015)</td>
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<td>(National Groundwater Information Center)</td>
<td>▪ Dam inflow, storage, release</td>
<td>▪ Weather data (1984-2015)</td>
<td>▪ DEM, Soil, Land use</td>
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<tr>
<td>▪ living, industrial, agricultural</td>
<td>▪ Dam inflow, storage, release</td>
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</tr>
</tbody>
</table>

1-1. Application of climate change scenarios

<table>
<thead>
<tr>
<th>Groundwater use data</th>
<th>Future groundwater use data</th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ Using the regression equation groundwater use data (1980-1999)</td>
<td>▪ Using the regression equation</td>
</tr>
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<td>▪ Resources from NGIC groundwater use data (2000-2015)</td>
<td>▪ Climate change scenario: HadGEM3-RA</td>
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<tr>
<td></td>
<td>RCP 4.5, 8.5(2020s, 2050s, 2080s)</td>
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2. Model Calibration Process

<table>
<thead>
<tr>
<th>SWAT Model</th>
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<tbody>
<tr>
<td>▪ Model run (1984-2014)</td>
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<td>▪ Warm-up (1984)</td>
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<td>▪ Dam &amp; weir inflow</td>
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<td>▪ Dam &amp; weir storage</td>
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<td>▪ Groundwater level variation</td>
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<td>▪ Dam operation (2005-2015)</td>
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3. Model Results

<table>
<thead>
<tr>
<th>Climate change Assessment</th>
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<tr>
<td>▪ Application of climate change scenarios</td>
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<td>▪ Climate change scenario: HadGEM3-RA RCP 4.5, 8.5</td>
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<tr>
<td>▪ Change rate of water budget</td>
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<td>▪ Change map of Ground water</td>
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</table>
Study Area

Geum River basin (9,645.5 km²)
- Average precipitation 1,323.1 mm
- Average temperature 12.2°C
**SWAT model**

- **Water balance**

\[
SW_t = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})
\]

- **Reservoir**

\[
V = V_{stored} + V_{flowin} - V_{flowout} + V_{PCP} - V_{evap} - V_{seep}
\]

- **Symbols and Definitions**

- $SW_t$ = Final soil water content (mm)
- $SW_0$ = Initial soil water content on day $i$ (mm)
- $R_{day}$ = Amount of precipitation on day $i$ (mm)
- $Q_{surf}$ = Amount of surface runoff on day $i$ (mm)
- $E_a$ = Amount of evapotranspiration on day $i$ (mm)
- $W_{seep}$ = Amount of water entering the vadose zone from the soil profile on day $i$ (mm)
- $Q_{gw}$ = Amount of return flow on day $i$ (mm)

- **Symbols and Definitions**

- $V$ = volume of water in the impoundment at the end of the day (m$^3$H$_2$O)
- $V_{stored}$ = volume of water stored in the water body at the beginning of the day (m$^3$ H$_2$O)
- $V_{flowin}$ = volume of water entering the water body during the day (m$^3$ H$_2$O)
- $V_{flowout}$ = volume of water flowing out of the water body during the day (m$^3$ H$_2$O)
- $V_{PCP}$ = volume of precipitation falling on the water body during the day (m$^3$ H$_2$O)
- $V_{evap}$ = volume of water removed from the water body by evaporation during the day (m$^3$ H$_2$O)
- $V_{seep}$ = volume of water lost from the water body by seepage (m$^3$ H$_2$O).
SWAT model

- **Groundwater**

### Shallow aquifer

\[ aq_{sh,i} = aq_{sh,i-1} + w_{rchrg,sh} - Q_{gw} - W_{revap} - W_{pump,sh} \]

- \( aq_{sh,i} \) = Amount of water stored in the shallow aquifer on day \( i \) (mm H₂O)
- \( aq_{sh,i-1} \) = Amount of water stored in the shallow aquifer on day \( i-1 \) (mm H₂O)
- \( w_{rchrg,sh} \) = Amount of recharge entering the shallow aquifer on day \( i \) (mm H₂O)
- \( Q_{gw} \) = Groundwater flow or base flow into the main channel on day \( i \) (mm H₂O)
- \( W_{revap} \) = Amount of water moving into the soil zone in response to water deficiencies on day \( i \) (mm H₂O)
- \( W_{pump} \) = Amount of water removed from the shallow aquifer by pumping on day \( i \) (mm H₂O)

### Groundwater flow / base flow

\[ Q_{gw} = \frac{8000 \cdot K_{sat}}{L_{gw}^2} h_{wtbl} \]

- \( Q_{gw} \) = Groundwater flow or base flow into the main channel on day \( i \) (mm H₂O)
- \( K_{sat} \) = hydraulic conductivity of the aquifer (mm/day)
- \( L_{gw} \) = Distance from the ridge or subbasin divide for the groundwater system to the main channel (m)
- \( h_{wtbl} \) = water table height (m)

- Extract HRU value at the point where the ground water monitoring system is installed.
- SWAT does not output the groundwater level as a result.
- \( SA_{ST} - GWQMN = \text{Groundwater variation} \)
- Actual average + (SA_{ST} - GWQMN) = Groundwater level
- \( SA_{ST} \): shallow aquifer storage (mm)
- \( GWQMN \): threshold water level in shallow aquifer for base flow (mm)
SWAT Input Data

- **WUS (Water Use input file, \(10^4\)m\(^3\))**
  - Consumptive water is a management tool that removes water from the basin.
  - This file is used to simulate removal of water for irrigation outside the watershed or removal of water for urban/industrial use.

- **WUPND**: Average daily water removal from the pond for the month
- **WURCH**: Average daily water removal from reach for the month
- **WUSHAL**: Average daily water removal from the shallow aquifer for the month
- **WUDEEP**: Average daily water removal from the deep aquifer for the month
SWAT Input Data

• **Future Groundwater use data**
  - **Groundwater use data** are available on the website of National Groundwater Information Center (NGIC).
  - The NGIC provides **monthly and yearly groundwater use data** at watersheds and administrative districts.
  - In this study, monthly groundwater from 2000 to 2015 use was divided into living, industrial, and agricultural use.
  - Estimated **future groundwater use data** using actual groundwater use data and **regression equation**.
Data for SWAT model evaluation

GIS Data

(a) DEM
- Elevation: 8 - 1608m
- (30m grid size)

(b) Soil
- Soil: Loam (24%) and sandy loam (58%)

(c) Land cover
- Land cover (2008): Forest (62%) and Rice paddy (15%)

Maps showing:
- DEM with elevation range
- Soil texture map with loam and sandy loam
- Land cover map with forest, rice paddy, and other categories
Data for SWAT model evaluation

2 Multi-purpose dam data

- **Daecheong dam (DCD)**
  - Total Storage: $1.49 \times 10^6 \text{ m}^3$
  - Sub-basin area: 3,204 km$^2$

- **Yongdam dam (YDD)**
  - Total Storage: $815 \times 10^6 \text{ m}^3$
  - Sub-basin area: 930 km$^2$
Data for SWAT model evaluation

3 Multi-function weir data

- **Sejong weir (SJ)**
  - Total Storage: $570 \times 10^6$ m$^3$

- **Gongju weir (GJW)**
  - Total Storage: $1,550 \times 10^6$ m$^3$

- **Bakjae weir (BJW)**
  - Total Storage: $2,420 \times 10^6$ m$^3$
Data for SWAT model evaluation

2 Multi-purpose Dam & 3 Multi-function weir Release and Storage data

• Yong-Dam Dam (YDD): 2001-2015
• Dae-Chung Dam (DCD): 1982-2015
• Sejong Weir (SJW): 2012-2015
• Gongju Weir (GJW): 2012-2015
• Bakjae Weir (BJW): 2012-2015
Data for SWAT model evaluation

5 Groundwater Level station data

- K-water GIMS (National Groundwater Information Center)
## Model Calibration and Validation

### SWAT parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Definition</th>
<th>Range</th>
<th>Adjusted Value</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td>YDD</td>
<td>DCD</td>
<td>SJW</td>
<td>GJW</td>
<td>BJW</td>
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<td><strong>Surface runoff</strong></td>
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<td>CH_N(2)</td>
<td>Manning’s “n” value for the tributary channel</td>
<td>0.01 to 30</td>
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<td><strong>Evapotranspiration</strong></td>
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<td>ESCO</td>
<td>Soil evaporation compensation coefficient</td>
<td>0 to 1</td>
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<td><strong>Groundwater</strong></td>
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<tr>
<td>GW_DELAY</td>
<td>Delay time for aquifer recharge (days)</td>
<td>0 to 500</td>
<td>150</td>
<td>50</td>
<td>30</td>
<td>31</td>
<td>31</td>
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<tr>
<td>GWQMN</td>
<td>Threshold water level in shallow aquifer for base flow (mm)</td>
<td>0 to 5000</td>
<td>1,000</td>
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<tr>
<td>ALPHA_BF</td>
<td>Base flow recession constant</td>
<td>0 to 1</td>
<td>0.2</td>
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<tr>
<td>REVAPMN</td>
<td>Threshold water level in shallow aquifer for revap (mm)</td>
<td>0 to 1000</td>
<td>750</td>
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<tr>
<td>GW_REVAP</td>
<td>Groundwater revap coefficient</td>
<td>0.02 to 0.2</td>
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<tr>
<td><strong>Reservoir</strong></td>
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</tr>
<tr>
<td>RES_ESA</td>
<td>Reservoir surface area when the reservoir is filled to the emergency spillway (ha)</td>
<td>-</td>
<td>3700</td>
<td>7420</td>
<td>350</td>
<td>350</td>
<td>350</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RES_EVOL</td>
<td>Volume of water needed to fill the reservoir to the emergency spillway (10⁴ m³)</td>
<td>-</td>
<td>81500</td>
<td>149000</td>
<td>570</td>
<td>1560</td>
<td>2500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RES_PSA</td>
<td>Reservoir surface area when the reservoir is filled to the principal spillway (ha)</td>
<td>-</td>
<td>3390</td>
<td>6750</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RES_PVOL</td>
<td>Volume of water needed to fill the reservoir to the principal spillway (10⁴ m³)</td>
<td>-</td>
<td>74250</td>
<td>124160</td>
<td>565</td>
<td>1554</td>
<td>2471</td>
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<td></td>
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<tr>
<td>RES_VOL</td>
<td>Initial reservoir volume(10⁴ m3)</td>
<td>-</td>
<td>39821</td>
<td>76857</td>
<td>546</td>
<td>1550</td>
<td>2471</td>
<td></td>
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<tr>
<td>RES_K</td>
<td>Hydraulic conductivity of the reservoir bottom (mm/hr)</td>
<td>0 to 1</td>
<td>0.3</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td></td>
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</tr>
<tr>
<td>EVRSV</td>
<td>Lake evaporation coefficient</td>
<td>0 to 1</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td></td>
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</tr>
</tbody>
</table>
Model Calibration and Validation

2 Multi-purpose Dam & 3 Multi-function weir

Model Calibration and Validation

5 Groundwater level

- **Calibration:** 5 years (2005-2009) / **Validation:** 6 years (2010-2015)

![Map of the region with groundwater level stations and rivers]
Climate Change Scenario

HadGEM3-RA RCP 4.5 and 8.5

Climate Change Scenario

HadGEM3-RA RCP 4.5 and 8.5

2020s: 2010-2039 / 2050s: 2040-2069 / 2080s: 2070-2099

Spring (3-5), Autumn (9-11), Winter (12-2): Precipitation and temperature increased.
Summer (6-8): Precipitation decreased and temperature increased.

- RCP 4.5
  - 2020s: +65.1 mm
  - 2050s: +115.6 mm
  - 2080s: +190.3 mm
  - Spring (3-5): +134.2 mm
  - Summer (6-8): -42.7 mm
  - Autumn (9-11): +19.6 mm
  - Winter (12-2): +12.5 mm
  - Total 2020s: +17.9 mm
  - Total 2050s: +181.5 mm
  - Total 2080s: +160.3 mm

- RCP 8.5
  - 2020s: +0.9 °C
  - 2050s: +1.9 °C
  - 2080s: +2.4 °C
  - Spring (3-5): +2.0 °C
  - Summer (6-8): +2.5 °C
  - Autumn (9-11): +1.5 °C
  - Winter (12-2): +0.9 °C
  - Total 2020s: +1.2 °C
  - Total 2050s: +3.2 °C
  - Total 2080s: +5.4 °C
Future groundwater use ($10^4$ m$^3$) data

- Comparison with historical data (2020s, 2050s, 2080s)

  - Summer (6-8)
    - CASS: 2020s (+32%), 2050s (+45%), 2080s (+53%)
    - BEMR: 2020s (+35%), 2050s (+49%), 2080s (+58%)
    - OCCS: 2020s (+42%), 2050s (+58%), 2080s (+69%)
    - BYBY: 2020s (+44%), 2050s (+62%), 2080s (+73%)
    - JSJS: 2020s (+37%), 2050s (+52%), 2080s (+62%)

Groundwater Use

- Spring
- Summer
- Autumn
- Winter
Assessment of GWU Impact on GWF

**Historical (1981-2005) Groundwater flow (mm)**

- When groundwater use was applied, groundwater decreased by 20 mm/yr.
Assessment of Climate Change

Future Precipitation (mm)

Historical (1981-2005)

RCP 4.5
2020s
Avg.: 1,415.6 mm (+13.7 mm)
RCP 4.5
2050s
Avg.: 1,589.7 mm (+187.8 mm)
RCP 4.5
2080s
Avg.: 1,514.0 mm (+112.0 mm)

RCP 8.5
2020s
Avg.: 1,472.0 mm (+70.1 mm)
RCP 8.5
2050s
Avg.: 1,558.3 mm (+156.4 mm)
RCP 8.5
2080s
Avg.: 1,621.0 mm (+219.1 mm)

2020s: 2010-2039
2050s: 2040-2069
2080s: 2070-2099
Assessment of Climate Change

Future Discharge (mm)

Historical (1981-2005)

- RCP 4.5
  - 2020s: +455.22 mm
  - 2050s: +388.74 mm
  - 2080s: +883.41 mm

- RCP 8.5
  - 2020s: +361.65 mm
  - 2050s: +526.36 mm
  - 2080s: +400.70 mm

Max: +455.22 mm
Min: -41.98 mm
Avg.: +24.28 mm
* In comparison with Historical

Max: +388.74 mm
Min: -16.43 mm
Avg.: +93.74 mm
* In comparison with Historical

Max: +883.41 mm
Min: +10.52 mm
Avg.: +148.79 mm
* In comparison with Historical

Max: +361.65 mm
Min: -96.65 mm
Avg.: -27.43 mm
* In comparison with Historical

Max: +526.36 mm
Min: +7.00 mm
Avg.: +109.75 mm
* In comparison with Historical

Max: +400.70 mm
Min: -136.91 mm
Avg.: +28.17 mm
* In comparison with Historical
Assessment of Climate Change

Future Evapotranspiration (mm)

Historical (1981-2005)

RCP 4.5
2020s

Max: +9.57 mm
Min: +67.40 mm
Avg.: +41.57 mm
* In comparison with Historical

RCP 4.5
2050s

Max: +31.91 mm
Min: +79.76 mm
Avg.: +56.16 mm
* In comparison with Historical

RCP 4.5
2080s

Max: +40.58 mm
Min: +85.37 mm
Avg.: +64.05 mm
* In comparison with Historical

RCP 8.5
2020s

Max: +6.17 mm
Min: +63.02 mm
Avg.: +36.96 mm
* In comparison with Historical

RCP 8.5
2050s

Max: +48.93 mm
Min: +87.21 mm
Avg.: +70.32 mm
* In comparison with Historical

RCP 8.5
2080s

Max: +68.59 mm
Min: +91.94 mm
Avg.: +78.51 mm
* In comparison with Historical

Avg.: 520.15 mm
Assessment of Climate Change

Future Groundwater flow (mm)

Historical (1981-2005)

 Avg.: 346.60 mm

RCP 4.5

2020s

Max : +89.78 mm
Min : +6.90 mm
Avg.: +7.14 mm
* In comparison with Historical

2050s

Max : +68.62 mm
Min : +13.92 mm
Avg.: +27.94 mm
* In comparison with Historical

2080s

Max : +196.39 mm
Min : +17.16 mm
Avg.: +40.67 mm
* In comparison with Historical

RCP 8.5

2020s

Max : +33.03 mm
Min : -20.15 mm
Avg.: -20.53 mm
* In comparison with Historical

2050s

Max : +124.88 mm
Min : +7.84 mm
Avg.: +32.62 mm
* In comparison with Historical

2080s

Max : +81.70 mm
Min : -35.11 mm
Avg.: -4.53 mm
* In comparison with Historical
Assessment of Climate Change

Future Groundwater flow (mm) changes

Historical (1981-2005)

- 2020s: 2010-2039
- 2050s: 2040-2069
- 2080s: 2070-2099

RCP 4.5
- 2020s
  - Max: +89.78 mm
  - Min: +6.90 mm
  - Avg.: +7.14 mm
  * In comparison with Historical

- 2050s
  - Max: +68.62 mm
  - Min: +13.92 mm
  - Avg.: +27.94 mm
  * In comparison with Historical

- 2080s
  - Max: +196.39 mm
  - Min: +17.16 mm
  - Avg.: +40.67 mm
  * In comparison with Historical

RCP 8.5
- 2020s
  - Max: +33.03 mm
  - Min: -20.15 mm
  - Avg.: -20.53 mm
  * In comparison with Historical

- 2050s
  - Max: +124.88 mm
  - Min: +7.84 mm
  - Avg.: +32.62 mm
  * In comparison with Historical

- 2080s
  - Max: +81.70 mm
  - Min: -35.11 mm
  - Avg.: -4.53 mm
  * In comparison with Historical
Assessment of Climate Change

Future Groundwater Level (EL.m) changes

BYBY

2020s: -0.20 m 2050s: +0.05 m 2080s: -0.11 m

Summer PCP: +34.9 % ET: +9.8 %

RCP 4.5

RCP 8.5

CASS

2020s: +0.03 m 2050s: +0.06 m 2080s: +0.04 m

RCP 4.5

RCP 8.5

OCCS

2020s: -0.08 m 2050s: +0.00 m 2080s: +0.05 m

RCP 4.5

RCP 8.5

BEMR

2020s: -0.04 m 2050s: +0.01 m 2080s: +0.00 m

Summer PCP: -13.5 % ET: -0.6 %

RCP 4.5

RCP 8.5

JSJS

2020s: +0.21 m 2050s: +0.18 m 2080s: +0.24 m

Summer PCP: +23.0 % ET: +4.9 %

RCP 4.5

RCP 8.5

Average variation of future groundwater level at 5 station

Spring(3-5) Future groundwater level RCP 4.5: ▲, RCP 8.5: ▼

RCP 4.5: +0.08 m (2020s: -0.13 m, 2050s: -0.10 m, 2080s: +0.46 m)
RCP 8.5: -0.05 m (2020s: -0.15 m, 2050s: +0.15 m, 2080s: -0.16 m)

Summer(6-8) Future groundwater level RCP 4.5 and RCP 8.5: ▼

RCP 4.5: -0.03 m (2020s: -0.79 m, 2050s: +1.13 m, 2080s: -0.43 m)
RCP 8.5: -1.19 m (2020s: -1.08 m, 2050s: -1.50 m, 2080s: -0.99 m)

Autumn(9-11) Future groundwater level RCP 4.5 and RCP 8.5: ▲

RCP 4.5: +0.55 m (2020s: +0.64 m, 2050s: +0.24 m, 2080s: +0.78 m)
RCP 8.5: +0.04 m (2020s: +0.21 m, 2050s: +0.08 m, 2080s: -0.16 m)

Winter(12-2) Future groundwater level RCP 4.5: ▼, RCP 8.5: ▲

RCP 4.5: -0.01 m (2020s: -0.02 m, 2050s: -0.05 m, 2080s: +0.04 m)
RCP 8.5: +0.07 m (2020s: +0.01 m, 2050s: -0.01 m, 2080s: +0.21 m)
Findings and Future researches

- The purpose of this study is to evaluate future climate change impact on groundwater level behavior considering future groundwater use in Geum River basin (9,645.5 km²).

1. HadGEM3-RA RCP 4.5 & 8.5 Climate Change Scenarios
   - Spring(3-5), Autumn(9-11), Winter(12-2): Precipitation and Temperature increased.
   - **Summer(6-8):** Precipitation decreased (RCP 4.5 : -42.7 mm, RCP 8.5 : -55.4 mm) and temperature increased (RCP 4.5 : +2.5 °C, RCP 8.5 : +4.2 °C).

2. Future groundwater use (GWU) condition
   - Big increase of GWU in summer period.
   - Future GWU increased from 32 to 44% in 2020s, from 45 to 62% in 2050s, and from 53 to 73% in 2080s.

3. Future groundwater level (GWL) changes
   - **Spring(3-5):** increased by 0.08 m in RCP 4.5, decreased by 0.05 m in RCP 8.5 scenario
   - **Summer(6-8):** decreased by 0.03 m and 1.19 m in RCP 4.5 and RCP 8.5 scenarios respectively
   - **Autumn(9-11):** increased by 0.55 m and 0.04 m in RCP 4.5 and RCP 8.5 scenarios respectively
   - **Winter(12-2):** decreased by 0.01 m in RCP 4.5, increased by 0.07 m in RCP 8.5 scenario
Thank You

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