How sensitive are rainfall interception models to the canopy parameters of semi-arid forests?

Marinos Eliades\textsuperscript{1}, Adriana Bruggeman\textsuperscript{1}, Hakan Djuma\textsuperscript{1}, Maciek W. Lubczynski\textsuperscript{2}

\textsuperscript{1}Energy, Environment and Water Research Center, The Cyprus Institute, Nicosia, Cyprus
\textsuperscript{2}University of Twente, ITC, Enschede, Netherlands
Introduction:

- Rainfall interception: 6 – 45% of the gross rainfall
- Rainfall interception models: rely on plant parameters
- Canopy storage capacity ($S$)
- Canopy cover fraction ($c$)

Objective: Examine the sensitivity of three commonly used rainfall interception models (Rutter, Gash and Liu) to the canopy storage capacity ($S$) and to the canopy cover fraction ($c$)

Study site$^{1,2}$: *Pinus brutia* forest, Cyprus

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevation (m)</td>
<td>620 - 655</td>
</tr>
<tr>
<td>Mean slope (degrees)</td>
<td>25</td>
</tr>
<tr>
<td>Aspect</td>
<td>North</td>
</tr>
<tr>
<td>Forest density (trees ha$^{-1}$)</td>
<td>200</td>
</tr>
<tr>
<td>Average annual rainfall (mm)</td>
<td>425</td>
</tr>
<tr>
<td>Minimum annual rainfall (mm)</td>
<td>169 (2007/2008)</td>
</tr>
<tr>
<td>Maximum annual rainfall (mm)</td>
<td>725 (2018/2019)</td>
</tr>
<tr>
<td>Daily max. temperature (°C)</td>
<td>34 (July)</td>
</tr>
<tr>
<td>Daily min. temperature (°C)</td>
<td>4 (January)</td>
</tr>
</tbody>
</table>


Methodology:

Period 2016 - 2019
- 1 meteorological station (hourly)
- 28 manual throughfall gauges (after rainfall)
- 1 automatic throughfall gauge (hourly)
- Leaf area index
- 80 test runs per model: examine the effect of S and c onto the model performance
- Optimized parameters - Sensitivity analysis
- Model evaluation: Kling-Gupta efficiency (KGE) and percent bias (%)

Period 2008 - 2018
- 15 ICP forests\(^1\) throughfall gauges (weekly)
- Rainfall (daily)

\(^1\)International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests)
Methodology:

- **Rutter model**

\[ I_{\text{Rutter}} = cE_c \]

- **Gash model**

\[ I_{\text{Gash}} = c \sum_{j=1}^{m} P_j + c(nP_s) + c \frac{E_c}{R} \sum_{i=1}^{n} (P_i - P_s) \]

- **Liu model**

\[ I_{\text{Liu}} = c \left\{ S_c \left[ 1 - \exp \left( -\frac{c}{S} P \right) \right] \left[ 1 - \frac{E_c}{E_c} \right] + \frac{E_c}{E_c} P \right\} \]

- **C_c**: Water storages on the canopy surface (mm)
- **P**: Rainfall (mm)
- **E**: Potential evaporation (mm)
- **E_c**: Actual evaporation (mm)
- **D_c**: Canopy drainage (mm)
- **S_c**: Storage capacity of the canopy cover area (S /c) (mm)
- **c**: Canopy cover fraction
- **P_j**: Rainfall - m small rain events, insufficient to saturate the canopy (P < P_s)
- **P_i**: Rainfall - n large events that saturate the canopy (P ≥ P_s)
- **P_s**: Amount of water needed to saturate the canopy (mm)
- **R̄**: Mean rainfall rate (mm h⁻¹)
- **Ē_c**: Mean evaporation rate from the canopy area (Ē/c), (mm h⁻¹)

Results:

- Model performance (given by the KGE) of the three models (Rutter hourly and daily, Gash and Liu) with changing canopy cover fraction (c) and storage capacity (S)
Results:

- Percent bias between modelled and observed interception loss of the three models (Rutter hourly and daily, Gash and Liu) with changing canopy cover fraction (c) and storage capacity (S)
Results:

• Sensitivity analysis:
  Percent change of the input parameter $S$ ($dS/S$) and $c$ ($dc/c$) and the relative change to the model output for $S$ ($O(S)$) and $c$ ($O(c)$)

<table>
<thead>
<tr>
<th>dS/S, dc/c</th>
<th>$O(S)$</th>
<th>$O(c)^*$</th>
<th>$O(S)$</th>
<th>$O(c)$</th>
<th>$O(S)$</th>
<th>$O(c)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>8</td>
<td></td>
<td>6</td>
<td>11</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td></td>
<td>3</td>
<td>6</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td></td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>-5</td>
<td>-2</td>
<td>-3</td>
<td>0</td>
<td>-2</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>-10</td>
<td>-5</td>
<td>-6</td>
<td>-1</td>
<td>-5</td>
<td>0</td>
<td>-2</td>
</tr>
<tr>
<td>-20</td>
<td>-10</td>
<td>-12</td>
<td>-3</td>
<td>-13</td>
<td>0</td>
<td>-7</td>
</tr>
</tbody>
</table>

*Positive changes to the model output were not computed because the optimum $c$ was at the maximum (1).

• Optimized parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Rutter</th>
<th>Gash</th>
<th>Liu</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S$</td>
<td>2.23</td>
<td>1.43</td>
<td>1.37</td>
</tr>
<tr>
<td>$c$</td>
<td>1.00</td>
<td>0.40</td>
<td>0.57</td>
</tr>
<tr>
<td>$E$</td>
<td>0.07</td>
<td>0.07</td>
<td>0.07</td>
</tr>
<tr>
<td>$R$</td>
<td>0.37</td>
<td>0.44</td>
<td>0.40</td>
</tr>
</tbody>
</table>
Results:

- Rainfall interception ($I_{measured}$, $I_{Gash}$ and $I_{Liu}$) and model performance (KGE Gash and Liu) per year
Conclusions:

• The Rutter model outperformed Gash and Liu models
• Gash and Liu had similar long-term model performance
• All models were more sensitive to changes in $c$ than to changes in $S$
• A range of canopy parameter values achieve similar high rainfall interception model performance
Thank you!

Contact: Marinos Eliades
m.eliades@cyi.ac.cy
www.cyi.ac.cy