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Application of the artificial neural network to regional frequency analysis for estimating rainfall quantiles at ungauged sites

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1. Background & Objectives

2. Methodology

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1. Background & Objectives

- Regional frequency analysis
  - To reduce uncertainties due to short data length
  - Can determine more reliable quantiles of the site by using all sites’ data in a region

- Widely applied approaches of regional frequency analysis
  - Index flood method
  - Regression technique
1. Background & Objectives

- Artificial neural network model (ANN)
  - Suggested by McCulloch and Pitts (1943)
  - Sensitive to model structure and input data
1. Background & Objectives

- Objectives
  - Determination of better ANN model to estimate quantiles
  - The assessment of performances for three different regional frequency analysis methods
1. Background & Objectives

2. Methodology

3. Application

4. Results

5. Conclusions & Future studies
2. Methodology

- Quantile regression technique (QRT-ANN)
  - Estimates quantiles directly for various return periods
  - Output layer of ANN model is quantiles at each rainfall gauging site
2. Methodology

- **Parameter regression technique (PRT-ANN)**
  - Estimates the parameters of probability distribution function
  - Quantiles are then estimated with the output of model (parameters)
2. Methodology

- Extreme gradient boosting algorithm
  - Proposed by Chen and Guestrin (2016)
  - Winning solution for classification and regression problems
  - Extreme gradient boosting refers to a class of ensemble machine learning algorithms
  - Uses weighted boosting algorithm to make prediction
  - Many hyperparameters to be optimized
2. Methodology

- Evaluation tools
  - Relative root mean square error (RRMSE)

\[
RRMSE_i(F) = \left[ \frac{1}{N_{sim}} \sum_{m=1}^{N_{sim}} \left( \frac{Q_i^{[m]}(F) - Q_i(F)}{Q_i(F)} \right) \right]^{1/2}
\]

- Root mean square error (RMSE)

\[
RMSE_i(F) = \left[ \frac{1}{N_{sim}} \sum_{m=1}^{N_{sim}} \left( Q_i^{[m]}(F) - Q_i(F) \right) \right]^{1/2}
\]

where \(Q_i^{[m]}(F)\) and \(Q_i(F)\) are quantiles for a given non-exceedance probability \(F\) in the \(m^{th}\) simulation and observation at site \(i\).
2. Methodology

- Evaluation tools
  - Bias
    \[ b_i(F) = \frac{1}{N_{sim}} \sum_{m=1}^{N_{sim}} Q_i^{[m]}(F) - Q_i(F) \]
  - Relative bias
    \[ Rb_i(F) = \frac{1}{N_{sim}} \sum_{m=1}^{N_{sim}} \frac{Q_i^{[m]}(F) - Q_i(F)}{Q_i(F)} \]
1. Background & Objectives

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3. Application

- Flow chart

1. Cluster sites by designed conditions
2. Conduct at-site frequency analysis
3. Select better ANN model
4. Generate new data set

- At-site frequency analysis
- Index flood method
- ANN models

5. Evaluate RRMSE, RMSE, bias and Rbias between quantiles from observation data

6. Repeat (4) to (6) 500 times for each site
7. Compare the results
3. Application

- Rainfall gauging site
  - Where daily annual maximum precipitation data fits into generalize extreme value (GEV) distribution examined by at-site frequency analysis
    - shape parameter $\beta < 0$, $x_0 + \frac{\alpha}{\beta} \leq x < \infty$
  - Also has over 30 years of record length
  - Select 113 sites among 615 sites in South Korea
3. Application

- **Input variables**
  - Variables that are suitable for Monte Carlo simulation
  - Topographical and hydrological data

<table>
<thead>
<tr>
<th>Variables</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAT</td>
<td>Latitude (°)</td>
</tr>
<tr>
<td>LONG</td>
<td>Longitude (°)</td>
</tr>
<tr>
<td>ALT</td>
<td>Altitude (m)</td>
</tr>
<tr>
<td>AM data</td>
<td>daily annual maximum of recent 30 years</td>
</tr>
</tbody>
</table>
3. Application

- Designed conditions
  - Factors that affect the accuracy of regional frequency analysis
  - Heterogeneity measure \( (H) \)
  - Number of sites in a region \( (N_{site}) \)

- 9 different Monte Carlo simulations
  - 3 cases in terms of \( H \) \( (H = 1, 2, 3) \)
  - 3 cases in terms of \( N_{site} \) \( (N_{site} = 5, 10, 15) \)
3. Application

- Region 1 \((H = 1, N_{site} = 5)\)
- Region 2 \((H = 2, N_{site} = 5)\)
- Region 3 \((H = 3, N_{site} = 5)\)
- Region 4 \((H = 1, N_{site} = 10)\)
- Region 5 \((H = 2, N_{site} = 10)\)
- Region 6 \((H = 3, N_{site} = 10)\)
- Region 7 \((H = 1, N_{site} = 15)\)
- Region 8 \((H = 2, N_{site} = 15)\)
- Region 9 \((H = 3, N_{site} = 15)\)
1. Background & Objectives

2. Methodology

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4. Results

5. Conclusions & Future studies
4. Results

- **PRT-ANN versus QRT-ANN**
  - Region 1, 2, and 3
4. Results

- PRT-ANN versus QRT-ANN
  - Region 4, 5, and 6
4. Results

- PRT-ANN versus QRT-ANN
  - Region 7, 8, and 9
4. Results

- Monte Carlo simulation 1, 2, and 3
4. Results

- Monte Carlo simulation 4, 5, and 6
4. Results

- Monte Carlo simulation 7, 8, and 9
1. Background & Objectives

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5. Conclusions & Future studies
5. Conclusions & Future studies

- PRT-ANN was more accurate than QRT-ANN
  - QRT-ANN predicted 11 output variables while PRT-ANN predicted 3 output variables
  - PRT-ANN showed the less uncertainty in estimating quantiles than QRT-ANN

- Statistical method
  - For $N_{site} = 5$, performance difference between at-site frequency analysis and index flood method is getting close with $H$ increases from 1 to 3
5. Conclusions & Future studies

- **Statistical method**
  - For $N_{site} = 10$ and $15$, at-site frequency analysis shows better performance than index flood method at $T \leq 5$ years and index flood method shows better performance than at-site frequency analysis at $T > 5$ years regardless of $H$

- **Data driven method**
  - PRT-ANN shows the better performance than PRT-XGB for higher return period ($T \geq 5$ years)
  - Average performance of PRT-ANN is better than PRT-XGB
5. Conclusions & Future studies

- Statistical method versus data driven method
  - Both machine learning models show better performance than at-site frequency analysis and index flood method.
5. Conclusions & Future studies

- **Future studies**
  - Frequency analysis of climate change scenario
  - Performance analysis of index flood method, population index flood, and ANN models with nonstationary rainfall data
Thank you