A comparative analysis of hydrological drought in the Rur catchment under human and natural impacts

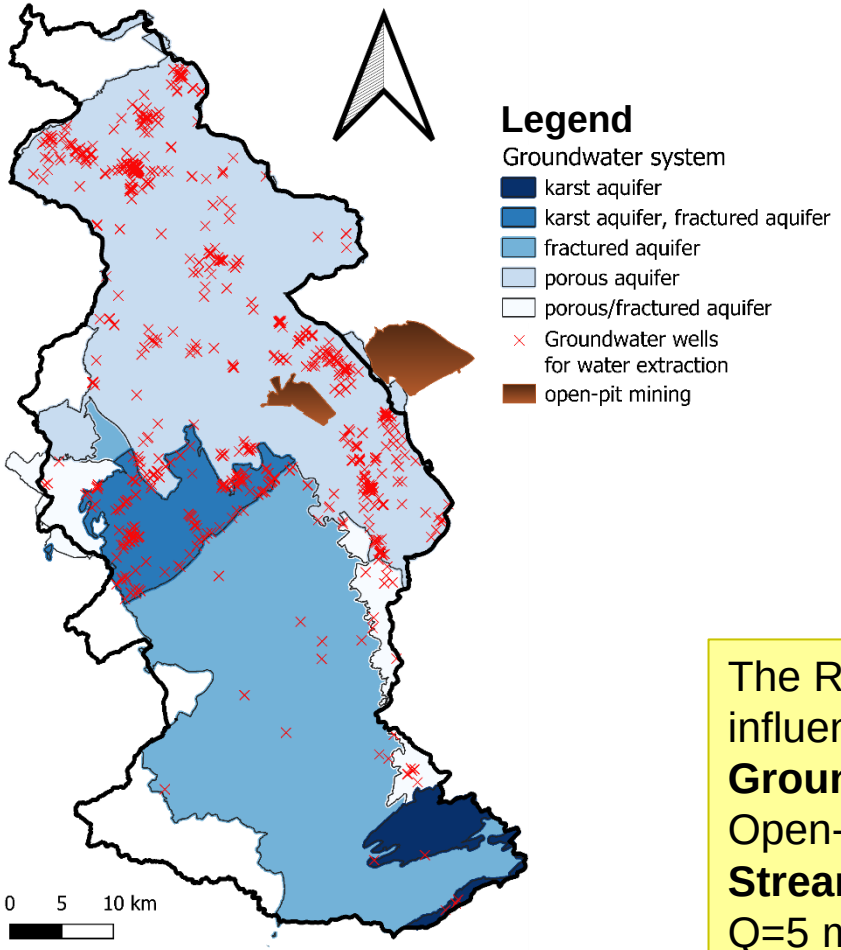
12th International Meuse Symposium

2026.09.09 | You Wu

IWW | RWTH AACHEN UNIVERSITY

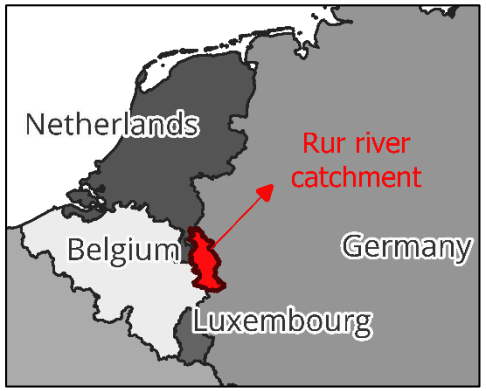
Study area and data: Rur River catchment

Groundwater system



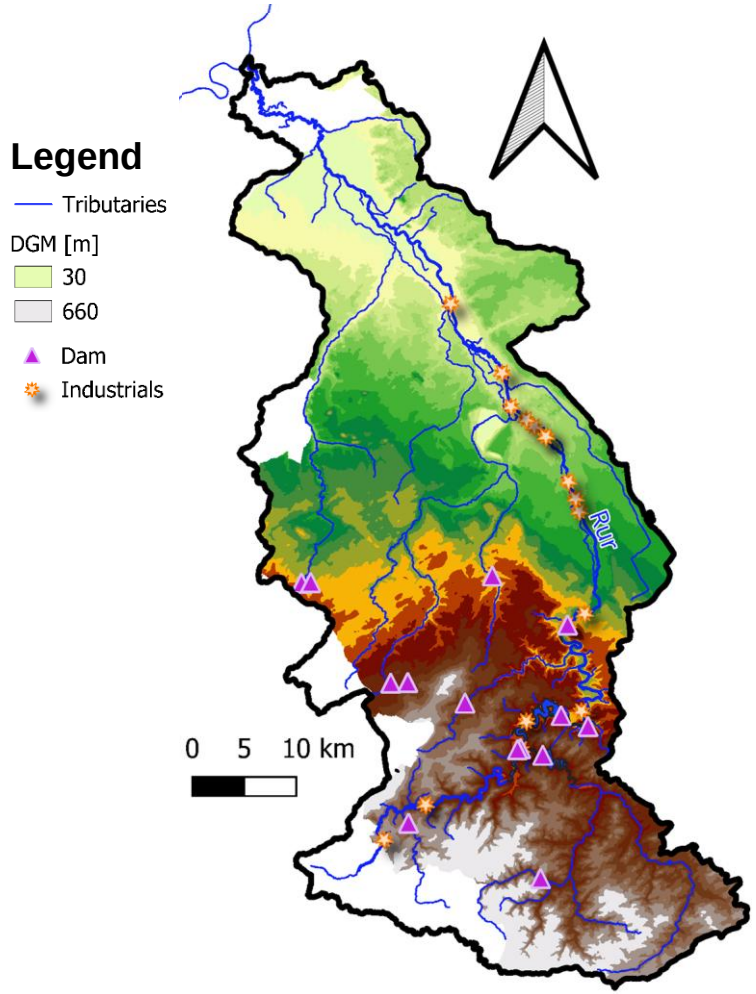
Rur River catchment:

- 2361 km²
- 90% in Germany
- Main cities: Aachen, Düren, Stolberg



The Rur River catchment is strongly influenced by human activities:
Groundwater: groundwater abstraction; Open-pit mining
Streamflow: dam system regulation (min. Q=5 m³/s)

Streamflow system



12th International Meuse Symposium
You Wu | Institut für Wasserbau und Wasserwirtschaft | RWTH Aachen
wu@iww.rwth-aachen.de

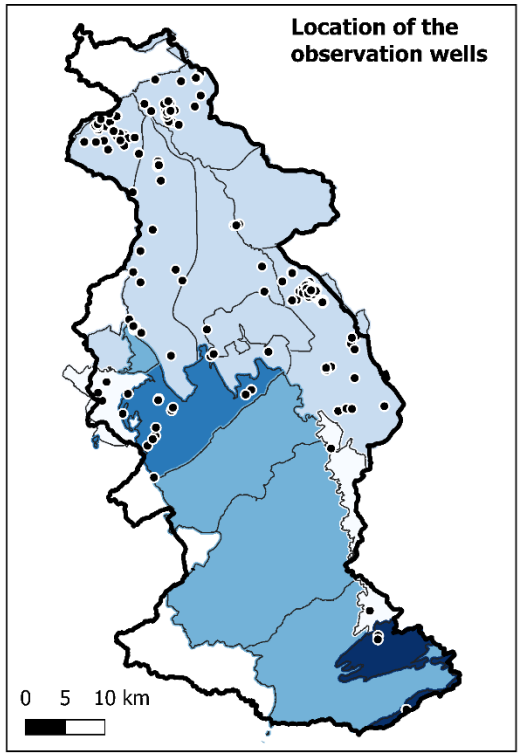
Study area and data

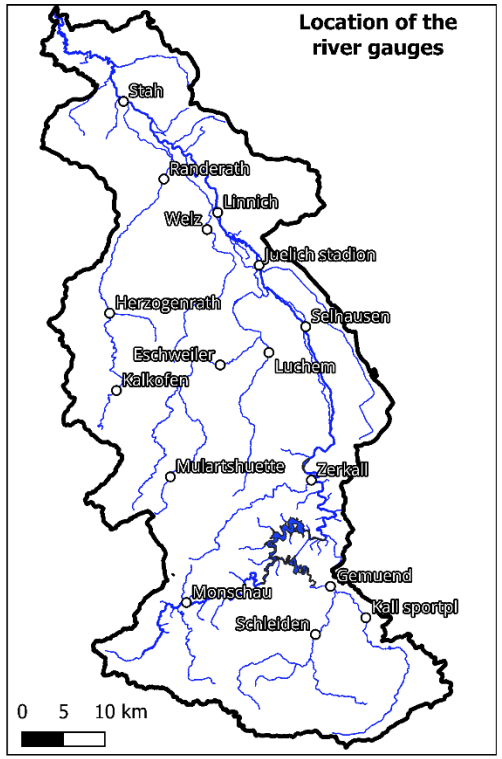
Study periods:
1991.01.01-2021.01.01

Groundwater data:
daily time series from 209 wells
(Source: Land NRW 2025)

Streamflow data:
daily time series from 16 gauges
(Source: Land NRW 2025)

Precipitation data:
Monthly raster data
(Source: DWD 2025)





Complex catchment (natural setting; human influences; groundwater-streamflow interaction):
- High variability
- High spatial heterogeneity -> different temporal dynamics

You Wu | Institut für Wasserbau und Wasserwirtschaft | RWTH Aachen
wu@iww.rwth-aachen.de

Workflow

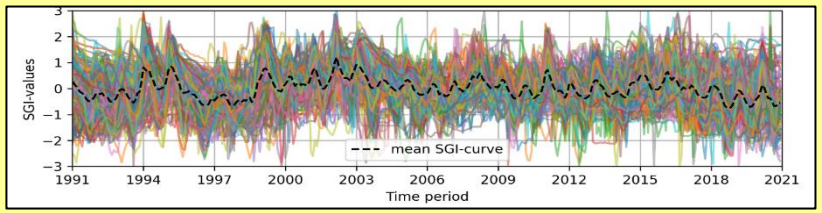
Groundwater gauge
(209 data points)

SGI
Standardized Groundwater Index

River water gauge
(16 data points)

SSI
Standardized Streamflow Index

High variability
-> a normalized range



You Wu | Institut für Wasserbau und Wasserwirtschaft | RWTH Aachen
wu@iww.rwth-aachen.de

Workflow

Groundwater gauge
(209 data points)

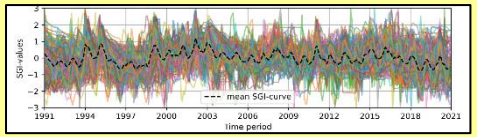
River water gauge
(16 data points)

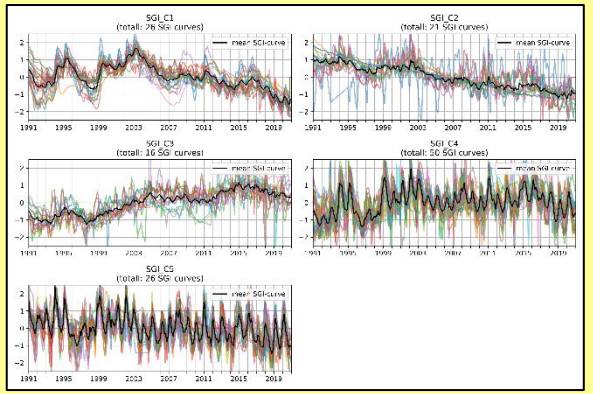
SGI
Standardized Groundwater Index

SSI
Standardized Streamflow Ind

Hierarchical cluster analysis

Different temporal dynamics
-> Classification into distinct clusters





You Wu | Institut für Wasserbau und Wasserwirtschaft | RWTH Aachen
wu@iww.rwth-aachen.de

Workflow

Groundwater gauge
(209 data points)

River water gauge
(16 data points)

SGI
Standardized Groundwater Index

SSI
Standardized Streamflow Index

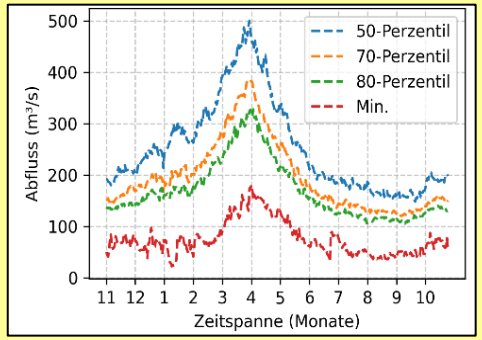
Hierarchical cluster analysis

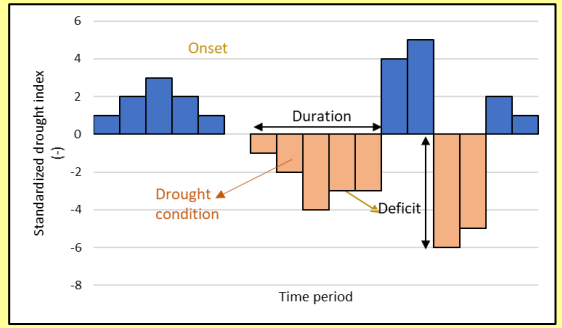
Variable threshold calculation
(80th Percentile)

Drought analysis based on Threshold-Level-Approach

Onset | Duration | Intensity | Severity

Drought event identification





You Wu | Institut für Wasserbau und Wasserwirtschaft | RWTH Aachen
wu@iww.rwth-aachen.de

Workflow

Groundwater gauge (209 data points)

River water gauge (16 data points)

SGI Standardized Groundwater Index

SSI Standardized Streamflow Index

Hierarchical cluster analysis

Variable threshold calculation (80th Percentile)

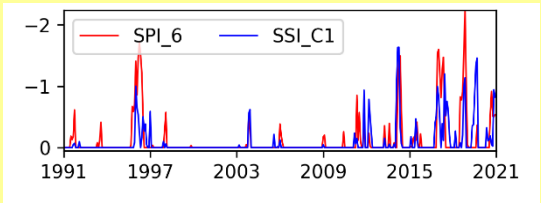
Drought analysis based on run theory

Onset | Duration | Intensity | Severity

Precipitation data

Cross-Correlation analysis
- SGI vs. SSI
- SGI vs. SPI
- SPI vs. SSI

Identify the main controls on drought propagation

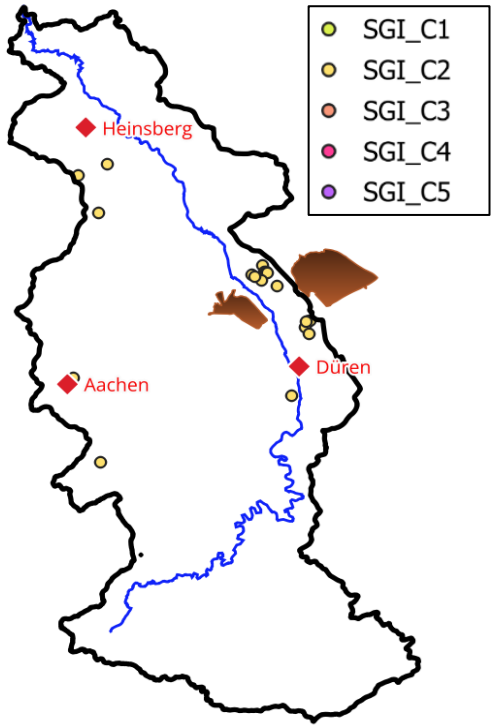


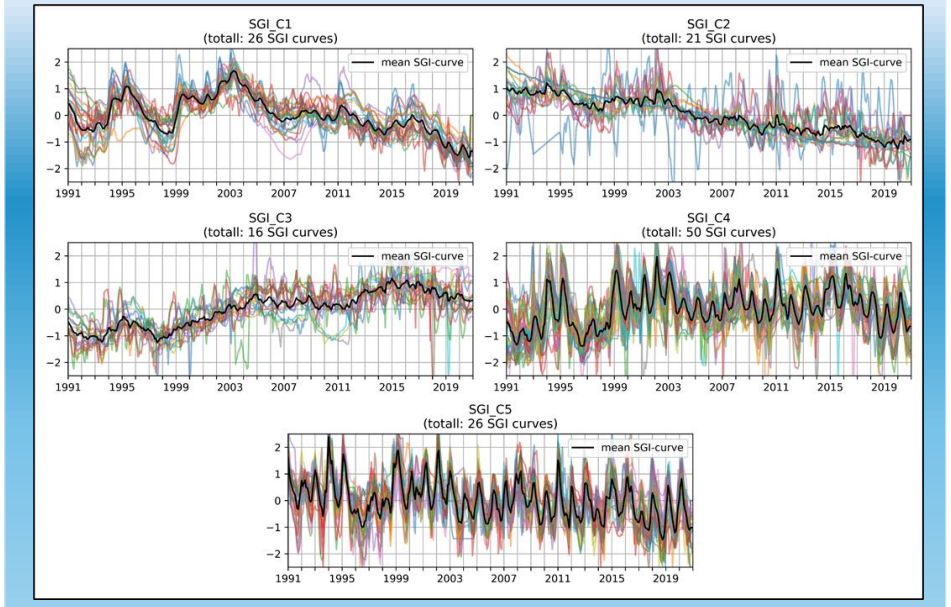
You Wu | Institut für Wasserbau und Wasserwirtschaft | RWTH Aachen
wu@iww.rwth-aachen.de

Result:
Cluster analysis on the groundwater system

Regional Distribution

- Near Rur (**SGI_C5**)
- Near open-pit mining (**SGI_C2**)



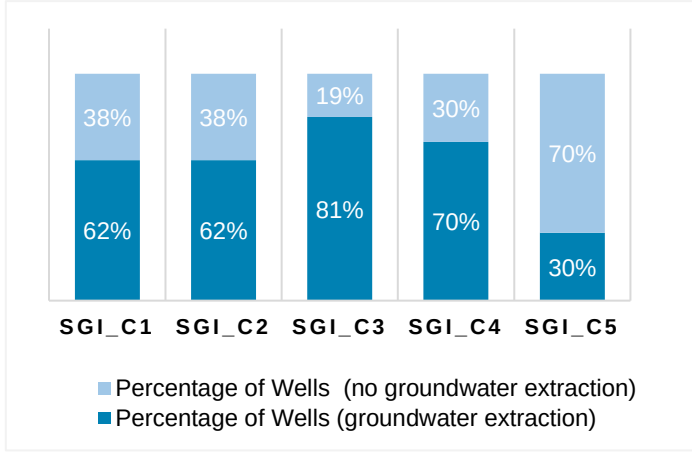


Temporal Dynamics

- Irregular pattern (**SGI_C1-3**)
- Declining trend (**SGI_C2**)
- Regular seasonal pattern(**SGI_C4-5**)

Influenced by water abstraction

- Higher proportion of no groundwater abstractions (**SGI_C5**)
- Higher proportion of groundwater abstractions (**SGI_C1-4**)



You Wu | Institut für Wasserbau und Wasserwirtschaft | RWTH Aachen
wu@iww.rwth-aachen.de

Result:
Cluster analysis on the groundwater system

Regional Distribution

- Near Rur (**SGI_C5**)
- Near open-pit mining (**SGI_C2**)

Influenced by water abstraction

- Higher proportion of no groundwater abstractions (**SGI_C5**)
- Higher proportion of groundwater abstractions (**SGI_C1-4**)

Temporal Dynamics

- Irregular pattern (**SGI_C1-3**)
- Declining trend (**SGI_C2**)
- Regular seasonal pattern(**SGI_C4-5**)

SGI_C1
SGI_C3

- Highly human-influenced clusters (e.g., wells near Heinsberg)
- Irregular Pattern

SGI_C4

- Regular seasonal pattern
- Moderate human-influenced clusters

SGI_C5

- Regular seasonal pattern
- Near-natural condition
- Influenced by Rur

SGI_C2

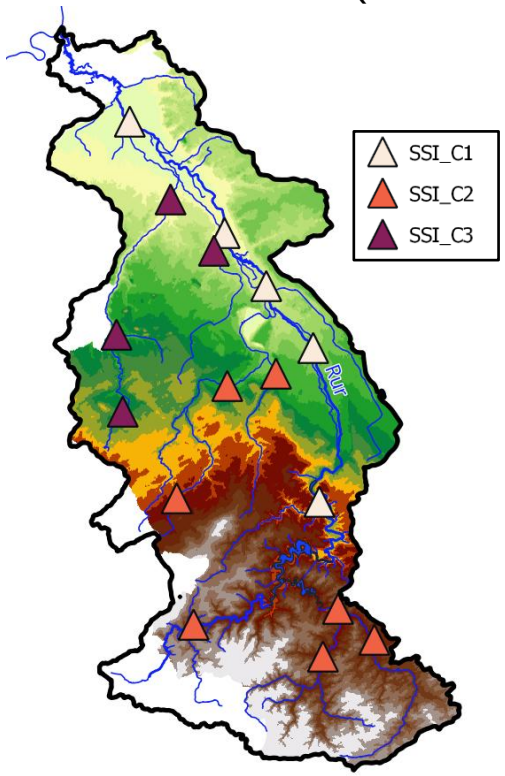
- Irregular Pattern (Decline)
- Highly influenced by nearby open-pit mining

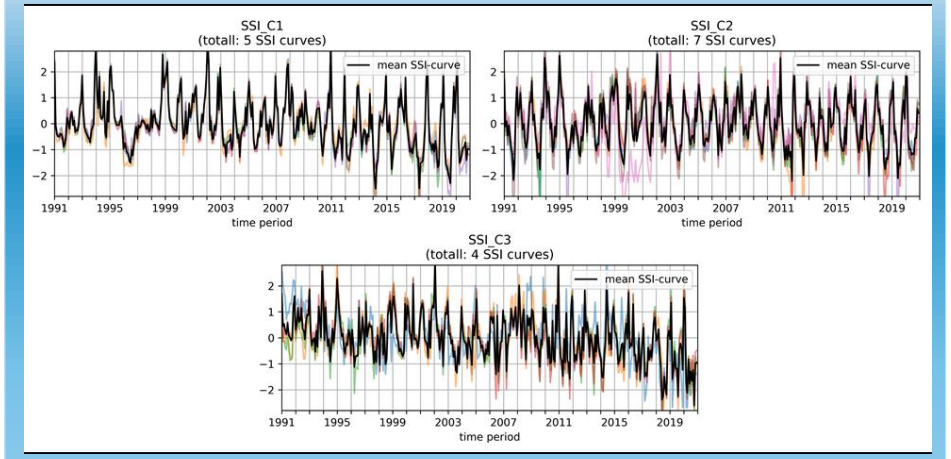
You Wu | Institut für Wasserbau und Wasserwirtschaft | RWTH Aachen
wu@iww.rwth-aachen.de

Result:
Cluster analysis on the streamflow system

Regional Distribution

- Mountains (**SSI_C2**)
- Lowlands (**SSI_C1, C3**)
- Rur downstream (**SSI_C1**)



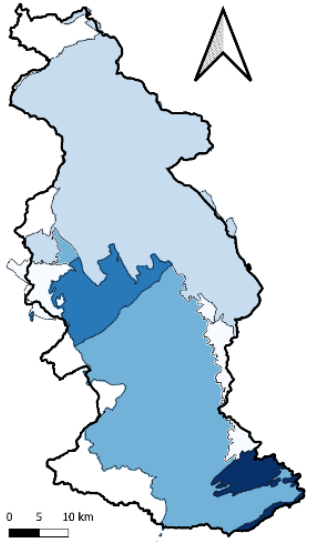


Temporal Dynamics

- Regular seasonal pattern
- Faster response to changing precipitation

Influenced by groundwater

- Mainly localized in porous aquifers (**SSI_C1, SSI_C3**)
- Mainly localized in fractured aquifers (**SSI_C2**)



You Wu | Institut für Wasserbau und Wasserwirtschaft | RWTH Aachen
wu@iww.rwth-aachen.de

Result:
Cluster analysis on the streamflow system

Regional Distribution

- Mountains (**SSI_C2**)
- Lowlands (**SSI_C1, C3**)
- Rur downstream (**SSI_C1**)

Influenced by groundwater

- Mainly localized in porous aquifers (**SSI_C1, SSI_C3**)
- Mainly localized in fractured aquifers (**SSI_C2**)

Temporal Dynamics

- Regular seasonal pattern
- Faster response to changing precipitation

SSI_C1

- Highly dam-regulation-influenced cluster (Rur downstream)
- Groundwater-streamflow-interaction

SSI_C2

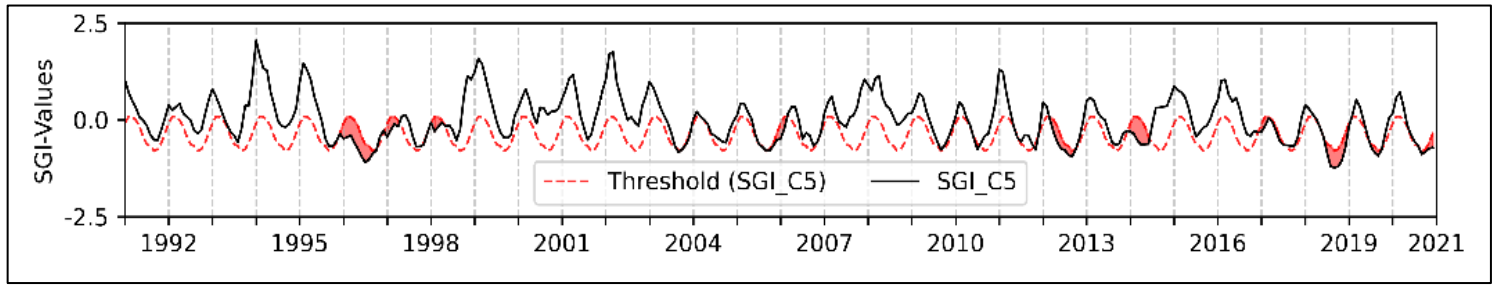
- Prompt response to variability in precipitation (mountain regions)

SSI_C3

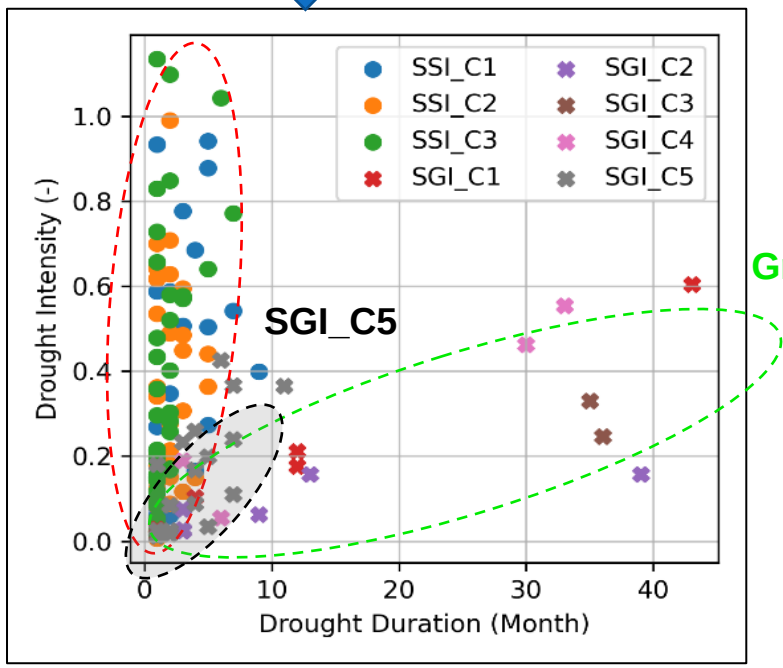
- Groundwater-streamflow-interaction

You Wu | Institut für Wasserbau und Wasserwirtschaft | RWTH Aachen
wu@iww.rwth-aachen.de

Result:
Hydrological drought characterizes



Streamflow

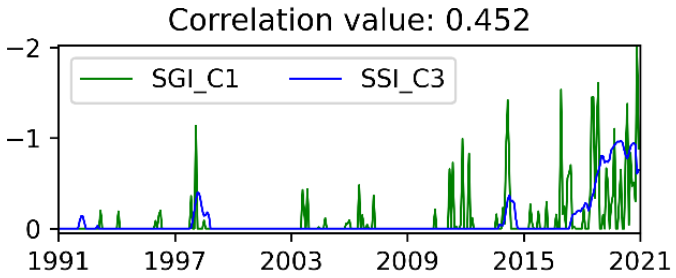


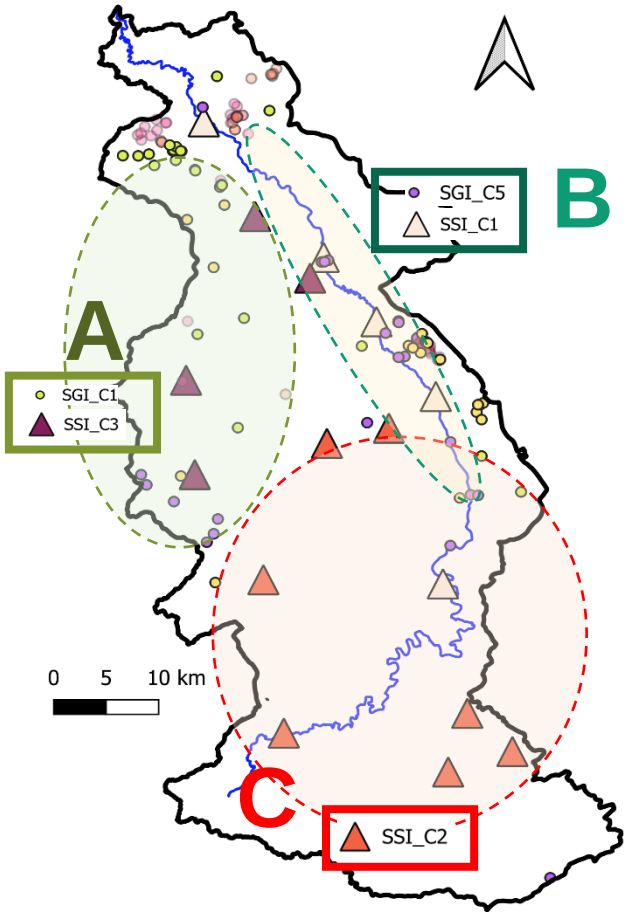
Groundwater

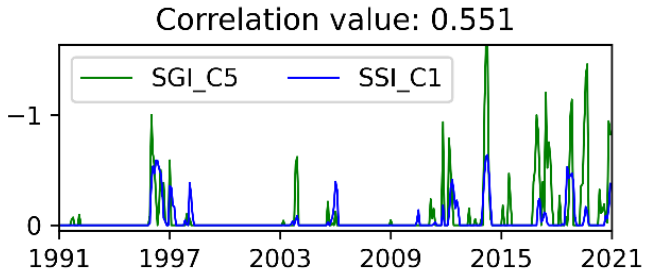
- **Groundwater vs. Streamflow:**
  - ➢ Groundwater: longer duration but low intensity
  - ➢ Streamflow: short duration but high intensity
- **SGI_C5:** streamflow-influenced clusters exhibit similar streamflow drought characteristics

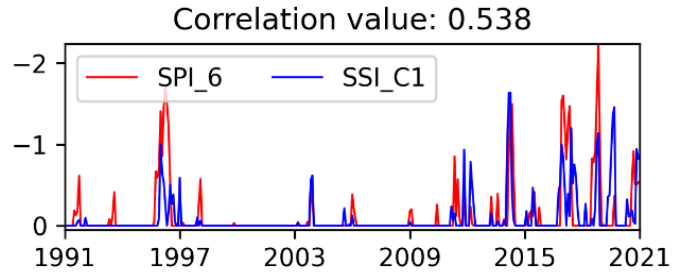
You Wu | Institut für Wasserbau und Wasserwirtschaft | RWTH Aachen
wu@iww.rwth-aachen.de

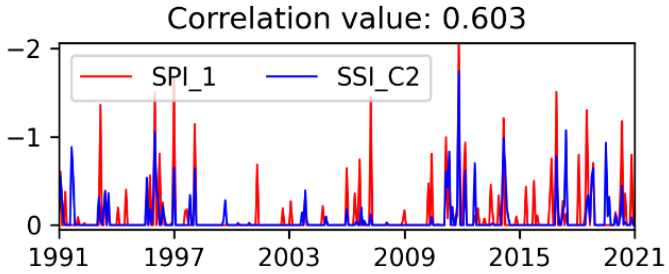
Result:
Cross-correlation analysis





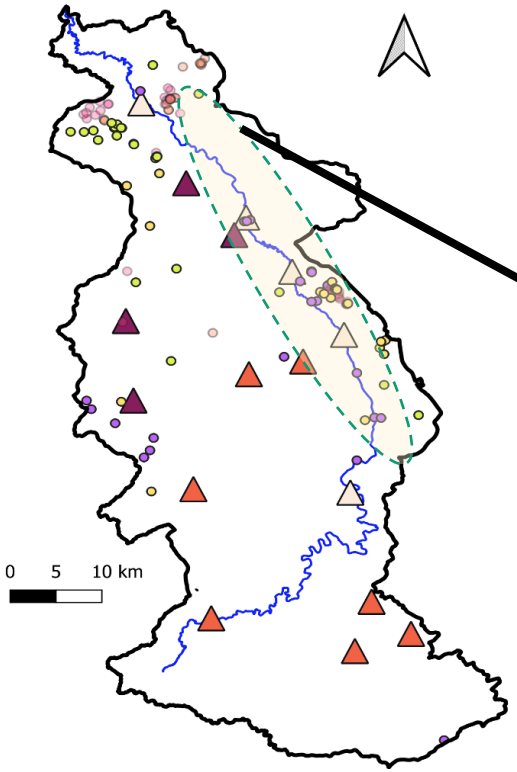


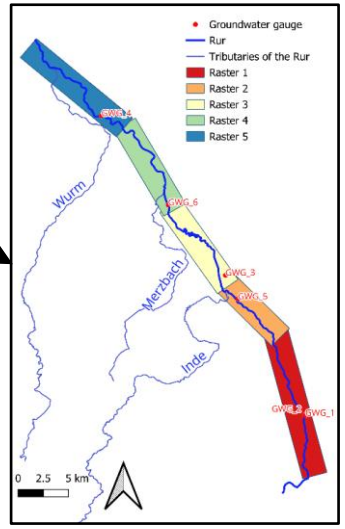




You Wu | Institut für Wasserbau und Wasserwirtschaft | RWTH Aachen
wu@iww.rwth-aachen.de

Excursus:
Groundwater-streamflow Interaction along the Rur river

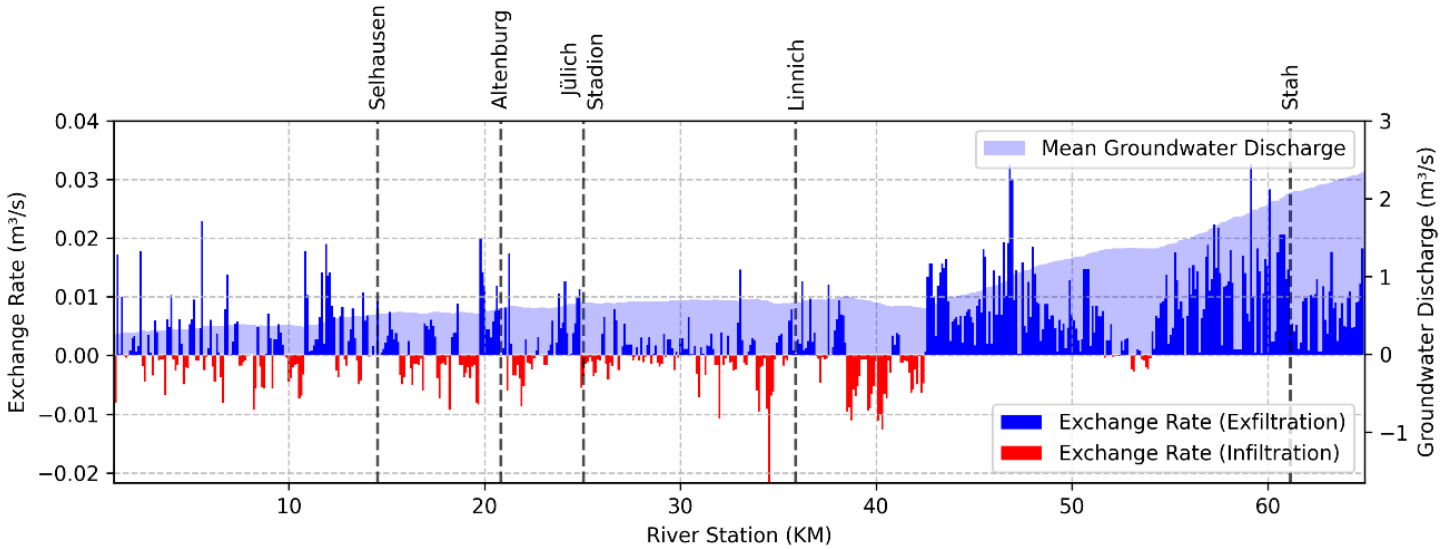




Hydrodynamic analysis:

- 2D-Groundwater model
- 1D-River model
- Groundwater-River Coupling

➢ A long-term simulation (1991-2020)



➢ Active groundwater-streamflow interaction along the Rur River

You Wu | Institut für Wasserbau und Wasserwirtschaft | RWTH Aachen
wu@iww.rwth-aachen.de

Conclusion

1. Groundwater responds slowly—but human activities reshape its dynamics

- Groundwater droughts generally last longer and exhibit lower intensity than streamflow droughts.
- Abstraction and open-pit mining weaken the natural response to precipitation deficits.

2. Streamflow responds rapidly—but local controls determine drought severity

- Streamflow droughts are generally shorter and more intense.
- Mountain streams respond primarily to short-term precipitation deficits.

3. Groundwater–streamflow interaction becomes crucial during prolonged drought

- Strong coupling was identified along the lower Rur..

You Wu | Institut für Wasserbau und Wasserwirtschaft | RWTH Aachen
wu@iww.rwth-aachen.de

Thank you for your attention!

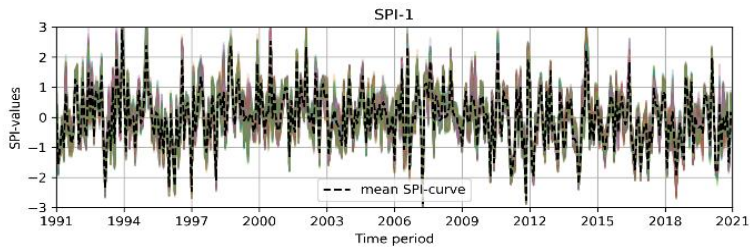
Photo by Philip Meier

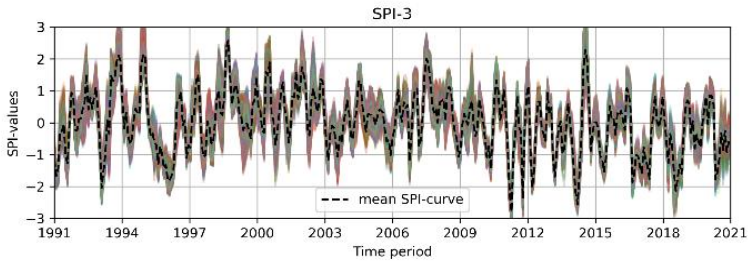
IWW | RWTH AACHEN UNIVERSITY

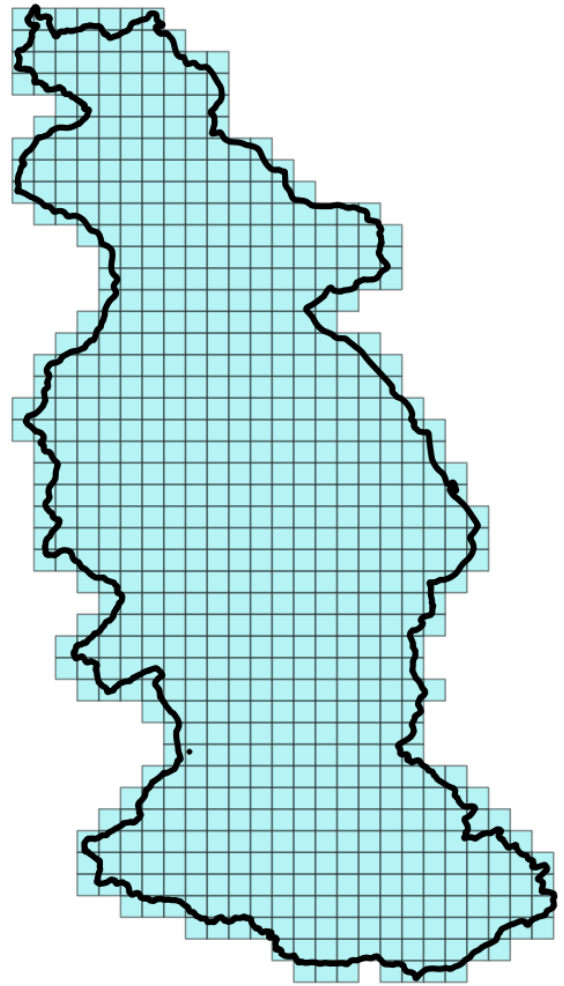
SPI Calculation

- Input Data: Monthly precipitation data from DWD Open-Portal (Raster data)
- Time zone: 1991.01.01-2020.12.31
- Grd: A grid of 620 cells (1 km x 1 km)
- Output: 620 SPI curves

- Result: homogeneous temporal variability

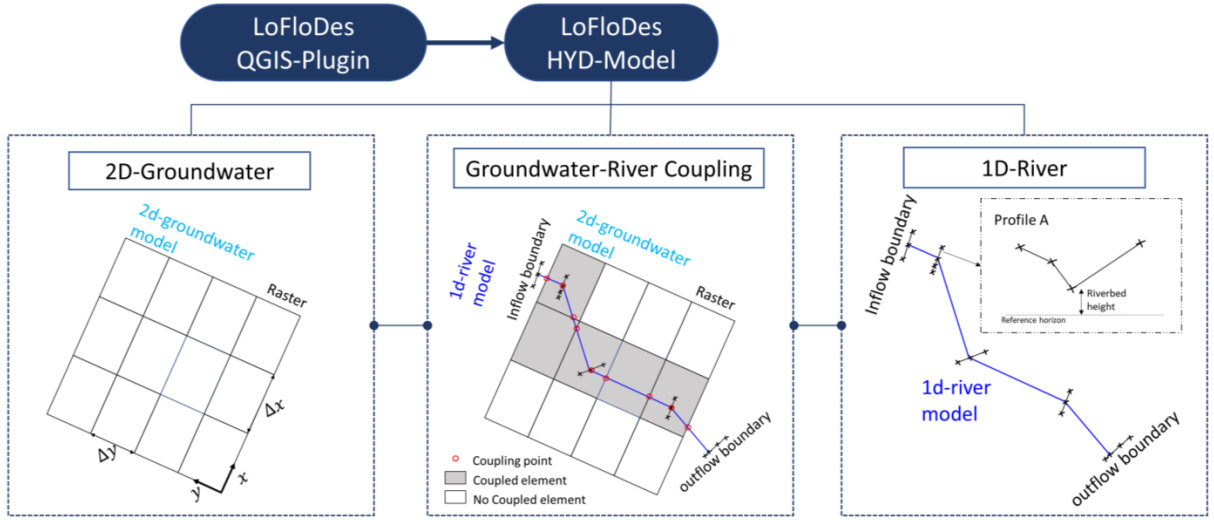






You Wu | Institut für Wasserbau und Wasserwirtschaft | RWTH Aachen
wu@iww.rwth-aachen.de

Groundwater-streamflow Coupling



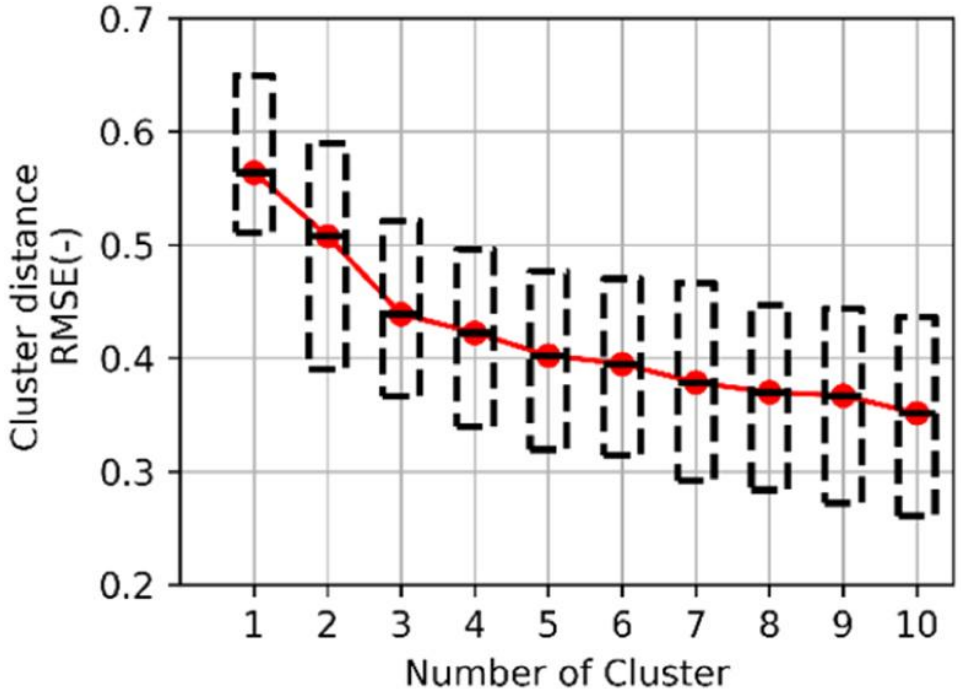
$$Q_{gw2rv} = kf_{rv} * L * \frac{r_{wetted}}{M_{rv}} * \Delta h$$

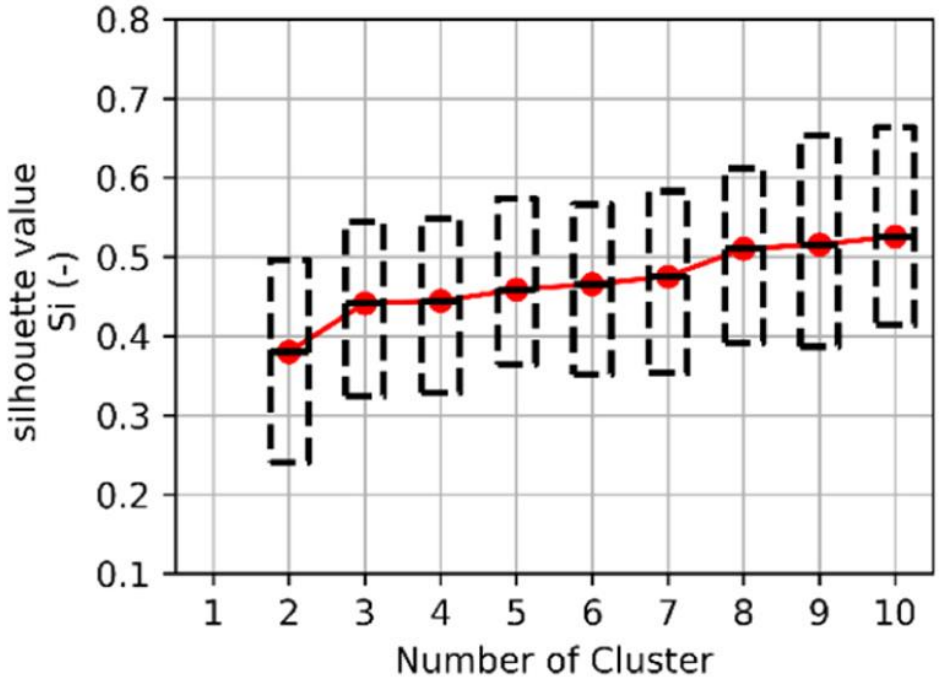
12th International Meuse Symposium
You Wu | Institut für Wasserbau und Wasserwirtschaft | RWTH Aachen
wu@iww.rwth-aachen.de

Cluster analysis

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - x_{i,mean})^2}$$

$$S_i = \frac{RMSE_b - RMSE_a}{\max(RMSE_a, \quad RMSE_b)}$$





You Wu | Institut für Wasserbau und Wasserwirtschaft | RWTH Aachen
wu@iww.rwth-aachen.de

Extended Cross-correlation analysis

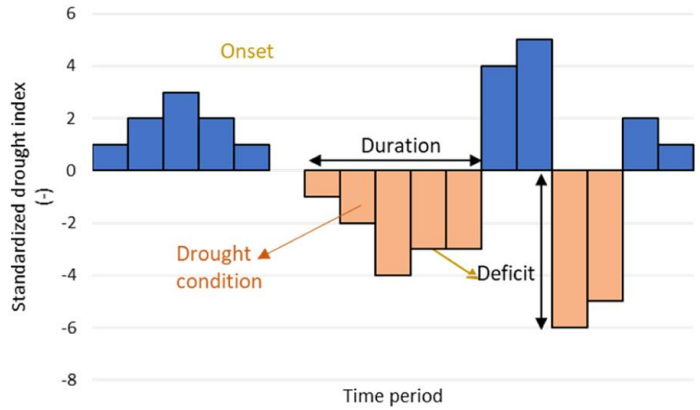
Table a)	0	1	2	3	4	5	6	7	8	9	10	11	Best lag time (M)	Range
SGI_C1 vs. SPI_1	**0.058**	0.078	0.073	0.081	0.075	0.073	0.059	0.069	0.043	0.034	0.039	0.055	3	0.048
SGI_C1 vs. SPI_3	**0.099**	0.127	0.152	0.168	0.167	0.166	0.141	0.118	0.110	0.122	0.137	0.145	3	0.069
SGI_C1 vs. SPI_6	**0.179**	0.188	0.189	0.175	0.148	0.136	0.146	0.156	0.167	0.178	0.192	0.203	11	0.067
SGI_C1 vs. SPI_12	**0.185**	0.208	0.217	0.223	0.224	0.225	0.227	0.235	0.248	0.259	0.267	0.277	11	0.092
SGI_C2 vs. SPI_1	**0.106**	0.156	0.121	0.109	0.134	0.085	0.098	0.118	0.126	0.083	0.030	0.057	1	0.126
SGI_C2 vs. SPI_3	**0.293**	0.281	0.279	0.255	0.252	0.235	0.259	0.233	0.160	0.130	0.138	0.129	0	0.164
SGI_C2 vs. SPI_6	**0.328**	0.337	0.333	0.329	0.289	0.217	0.181	0.174	0.176	0.162	0.132	0.137	0	0.205
SGI_C2 vs. SPI_12	**0.429**	0.394	0.364	0.320	0.278	0.243	0.226	0.240	0.274	0.278	0.264	0.262	0	0.203
SGI_C3 vs. SPI_1	**-0.017**	-0.001	0.009	0.012	0.016	0.013	0.027	0.033	0.044	0.056	0.040	0.038	9	0.073
SGI_C3 vs. SPI_3	**-0.084**	-0.079	-0.076	-0.080	-0.074	-0.056	-0.043	-0.010	0.011	0.026	0.037	0.039	11	0.122
SGI_C3 vs. SPI_6	**-0.114**	-0.112	-0.106	-0.093	-0.071	-0.049	-0.024	0.004	0.028	0.051	0.066	0.079	11	0.193
SGI_C3 vs. SPI_12	**-0.119**	-0.104	-0.084	-0.051	-0.020	0.012	0.048	0.074	0.095	0.115	0.129	0.133	11	0.252
SGI_C4 vs. SPI_1	**0.046**	0.086	0.115	0.119	0.086	0.070	0.050	0.021	0.026	0.042	0.044	0.031	3	0.098
SGI_C4 vs. SPI_3	**0.041**	0.096	0.140	0.144	0.120	0.115	0.113	0.098	0.082	0.077	0.066	0.058	3	0.103
SGI_C4 vs. SPI_6	**0.155**	0.197	0.207	0.202	0.186	0.170	0.147	0.136	0.133	0.126	0.108	0.092	2	0.115
SGI_C4 vs. SPI_12	**0.234**	0.258	0.214	0.188	0.154	0.122	0.106	0.095	0.084	0.080	0.071	0.060	1	0.198
SGI_C5 vs. SPI_1	**0.272**	0.248	0.232	0.182	0.153	0.194	0.188	0.132	0.063	0.072	0.045	-0.041	0	0.313
SGI_C5 vs. SPI_3	**0.518**	0.502	0.404	0.344	0.310	0.231	0.161	0.107	0.043	0.021	0.027	0.031	0	0.497
SGI_C5 vs. SPI_6	**0.675**	0.634	0.454	0.330	0.237	0.145	0.096	0.062	0.063	0.094	0.089	0.051	0	0.625
SGI_C5 vs. SPI_12	**0.604**	0.499	0.359	0.242	0.150	0.083	0.067	0.065	0.062	0.102	0.099	0.071	0	0.542

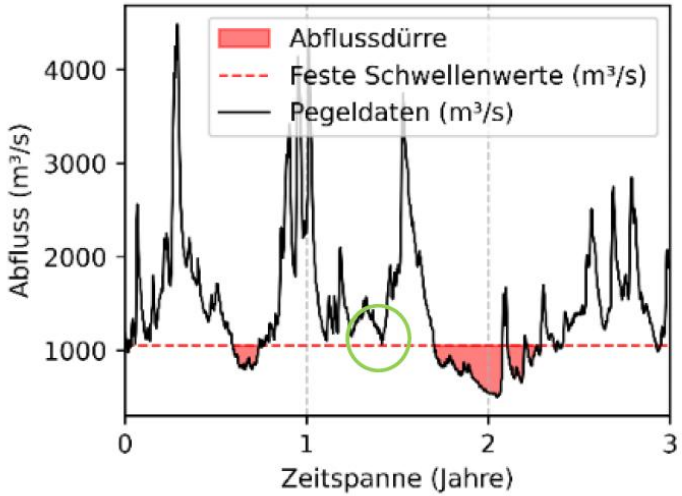
Table b)	0	1	2	3	4	5	Best lag time (M)	Range
SSI_C1 vs. SGI_C1	**0.304**	0.289	0.301	0.302	0.286	0.261	0	0.043
SSI_C2 vs. SGI_C1	**0.105**	0.128	0.140	0.135	0.136	0.128	2	0.035
SSI_C3 vs. SGI_C1	**0.452**	0.453	0.450	0.442	0.431	0.417	1	0.036
SSI_C1 vs. SGI_C2	**0.350**	0.345	0.333	0.329	0.311	0.277	0	0.073
SSI_C2 vs. SGI_C2	**0.161**	0.202	0.157	0.138	0.133	0.063	1	0.140
SSI_C3 vs. SGI_C2	**0.354**	0.366	0.362	0.350	0.343	0.258	1	0.108
SSI_C1 vs. SGI_C3	**-0.128**	-0.114	-0.103	-0.095	-0.093	-0.083	5	0.045
SSI_C2 vs. SGI_C3	**-0.020**	-0.013	-0.007	-0.006	-0.011	-0.009	3	0.014
SSI_C3 vs. SGI_C3	**-0.093**	-0.082	-0.076	-0.070	-0.066	-0.076	4	0.027
SSI_C1 vs. SGI_C4	**0.007**	0.032	0.046	0.040	0.030	0.022	2	0.040
SSI_C2 vs. SGI_C4	**0.099**	0.163	0.177	0.173	0.153	0.151	2	0.079
SSI_C3 vs. SGI_C4	**-0.066**	-0.043	-0.033	-0.028	-0.046	-0.069	3	0.042
SSI_C1 vs. SGI_C5	**0.551**	0.522	0.337	0.189	0.119	0.103	0	0.448
SSI_C2 vs. SGI_C5	**0.382**	0.378	0.245	0.149	0.110	0.145	0	0.272
SSI_C3 vs. SGI_C5	**0.395**	0.388	0.303	0.195	0.138	0.093	0	0.302

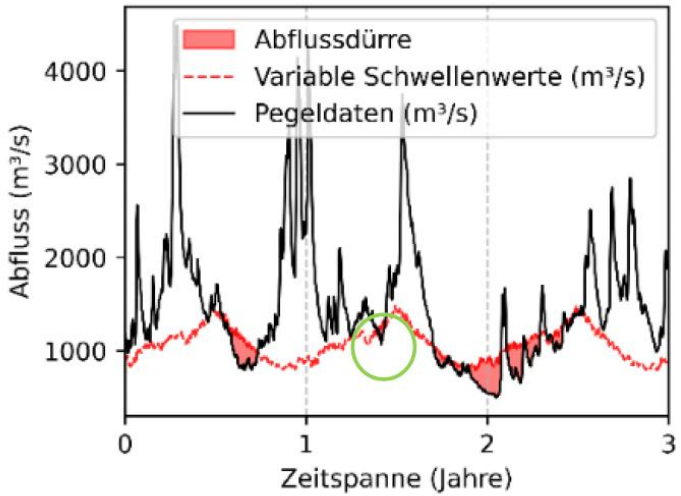
Table c)	0	1	2	3	4	5	6	7	8	9	10	11	Best lag time (M)	Range
SSI_C1 vs. SPI_1	**0.352**	0.187	0.076	0.086	0.142	0.039	0.111	0.061	0.114	0.125	0.065	0.036	0	0.317
SSI_C1 vs. SPI_3	**0.511**	0.361	0.287	0.242	0.201	0.106	0.172	0.118	0.117	0.143	0.195	0.232	0	0.405
SSI_C1 vs. SPI_6	**0.538**	0.347	0.253	0.234	0.206	0.124	0.175	0.137	0.206	0.223	0.214	0.103	0	0.435
SSI_C1 vs. SPI_12	**0.480**	0.361	0.309	0.264	0.216	0.134	0.105	0.092	0.095	0.092	0.059	0.038	0	0.442
SSI_C2 vs. SPI_1	**0.603**	0.087	0.057	0.051	0.091	0.020	0.098	-0.004	0.091	0.071	0.084	-0.018	0	0.621
SSI_C2 vs. SPI_3	**0.583**	0.192	0.146	0.149	0.122	0.020	0.105	0.028	0.037	0.040	0.113	0.069	0	0.563
SSI_C2 vs. SPI_6	**0.455**	0.209	0.118	0.080	0.082	0.020	0.061	-0.010	0.063	0.040	0.051	-0.001	0	0.465
SSI_C2 vs. SPI_12	**0.308**	0.137	0.083	0.048	0.010	-0.024	0.003	0.011	0.021	0.036	0.039	0.017	0	0.332
SSI_C3 vs. SPI_1	**0.564**	0.105	0.036	0.068	0.152	0.049	0.142	0.025	0.037	0.043	0.013	-0.031	0	0.595
SSI_C3 vs. SPI_3	**0.482**	0.223	0.185	0.192	0.172	0.038	0.100	0.039	0.039	0.020	0.003	-0.007	0	0.488
SSI_C3 vs. SPI_6	**0.490**	0.210	0.121	0.102	0.092	0.027	0.033	-0.033	-0.010	-0.002	0.042	-0.010	0	0.523
SSI_C3 vs. SPI_12	**0.282**	0.116	0.043	0.022	0.007	-0.018	-0.022	0.002	0.039	0.046	0.062	0.059	0	0.304

You Wu | Institut für Wasserbau und Wasserwirtschaft | RWTH Aachen
wu@iww.rwth-aachen.de

Threshold method







You Wu | Institut für Wasserbau und Wasserwirtschaft | RWTH Aachen
wu@iww.rwth-aachen.de