Status and stresses: a spatial analysis of near-surface drinking water resources in Germany

Kathrin Szillat, Kerstin Stahl, Jost Hellwig, Max Schmit

Contact: kathrin.szillat@hydrology.uni-freiburg.de

Background

- Almost 75 % of drinking water originates from groundwater (Umweltbundesamt, 2022).
- Various stress factors affect significantly the quality and quantity of groundwater resources.
- Combined effects of climate change and diverse physical and social factors pose a central challenge for current and future drinking water supply.
- To address this challenge, a good understanding of the varieties of situations needs to support tools and decision-making frameworks to manage groundwater sustainably and ensure resilient drinking water.
- Achieving sustainable drinking water management requires a systematic analysis of the heterogeneous natural, political-regulatory, and agro-economic conditions to identify transferable success factors.

Research question

- How are drinking water protection areas in Germany characterized?
- What are the differences from an administrative point of view?

Data

- Creation of unique dataset for all drinking water protection/ abstraction areas in Germany.
- Collection and preprocessing of publicly accessible data.
- Spatial dataset quantifies numerous potential characteristics and stress factors (m) for each of the (n) drinking water protection areas.
- Factors included are:

- hydrogeology and aquifer type
- groundwater recharge and precipitation
- elevation
- land use types:
- agriculture: livestock farming ( ) and different crop types( )
- human influence: water extraction rates, population density, population with connection to public water supply, water consumption, water costs
- water quality: water framework directive (WFD, 2022) chemical status, EEA nitrate groundwater measurements 2018-2021
- water quantity: drought response times, WFD quantitative status

Methods

- Correlation of data: Pearson parametric correlation test
- Cluster analysis:

Dissimilarity matrix: The dataset exists of numerical and categorical variables. As input for the cluster analysis we use the dissimilarity coefficient of Gower (1971):

$$d_{wG,ij} = \frac{\sum_{t=1}^{p} \delta_{ijt} d_{ijt} w_t}{\sum_{t=1}^{p} \delta_{ijt} w_t}$$

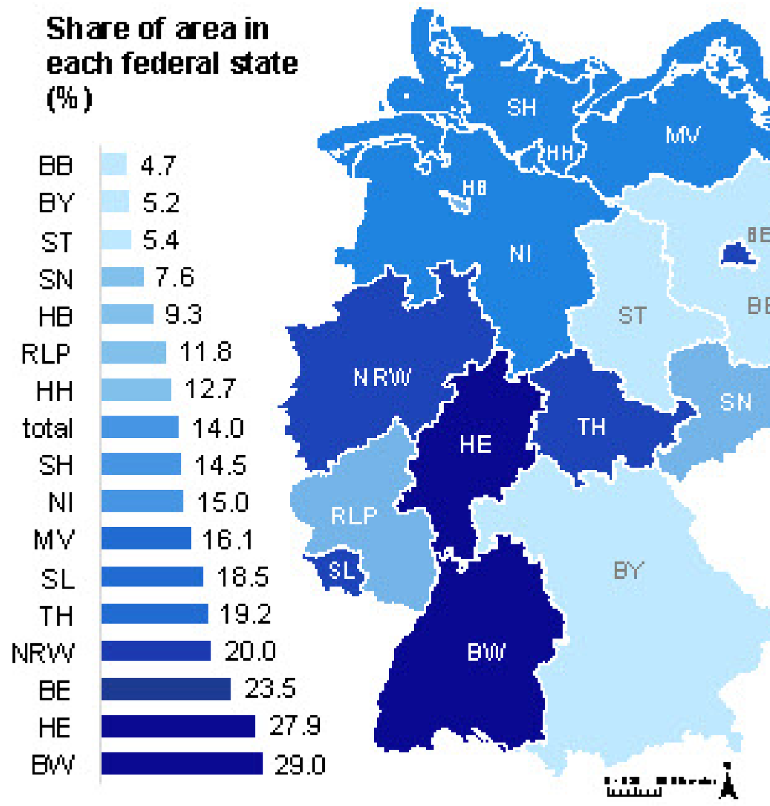
Hierarchical Clustering with Ward's minimum variance method: minimizing the total within-cluster variance.

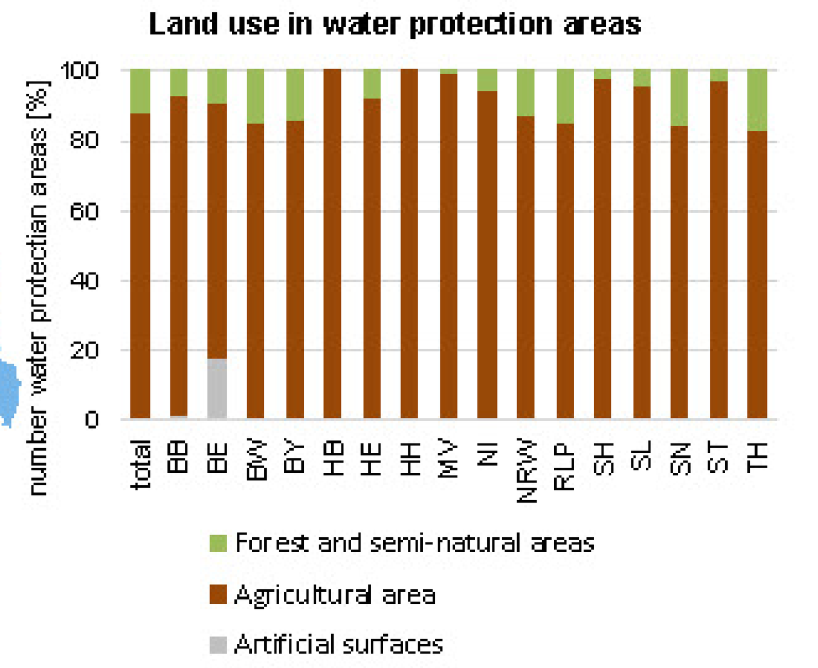
Average silhouette method: The optimal number of clusters k is the one that maximize the average silhouette over a range of possible values for k. It evaluates the relative closeness of the individual entities to their clusters (Kaufman and Rousseeuw, 1990).

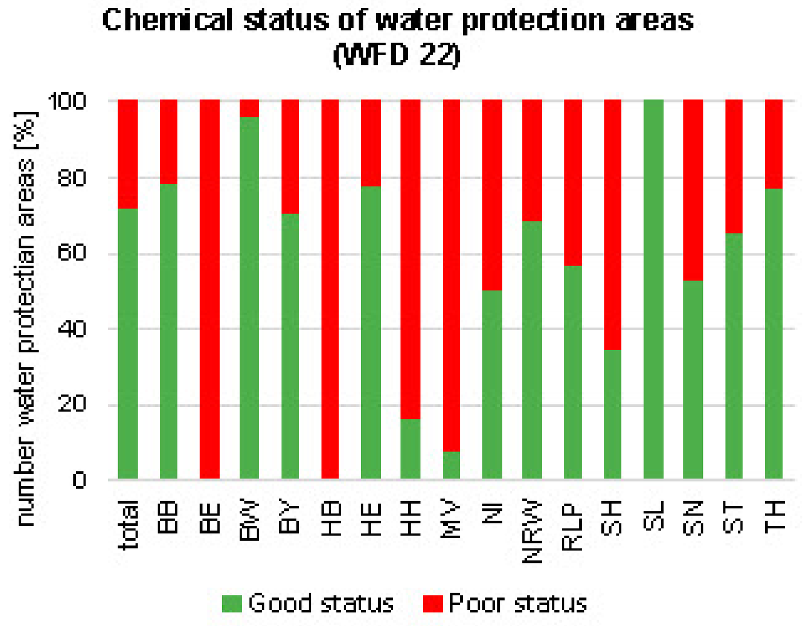
$$s(i) = \frac{b(i) - a(i)}{\max(a(i), b(i))}$$

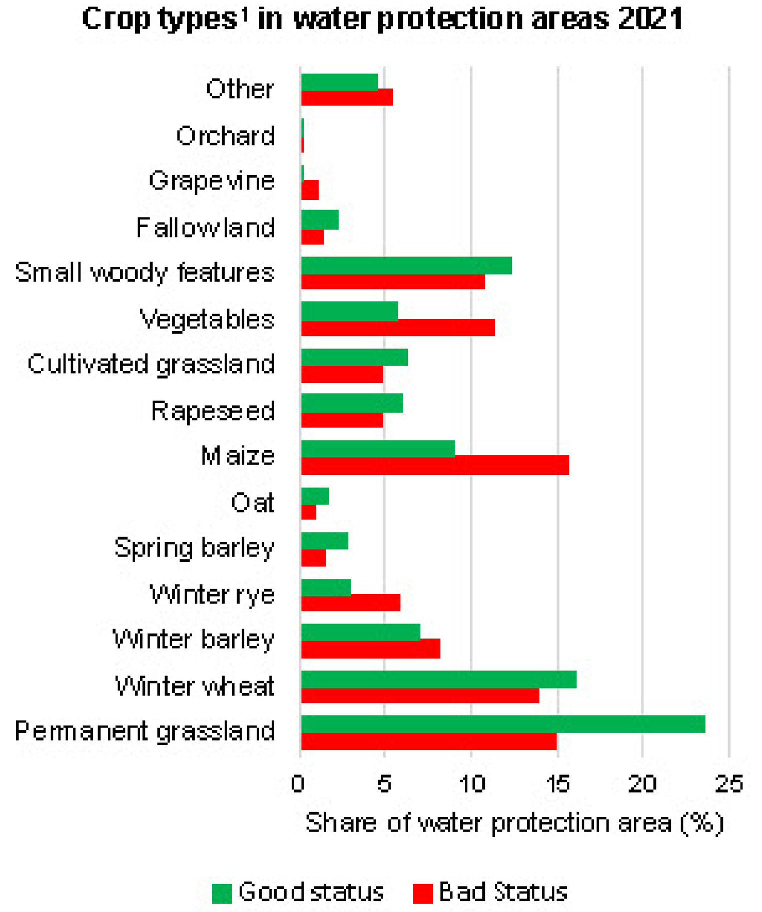
Results: administrative point of view

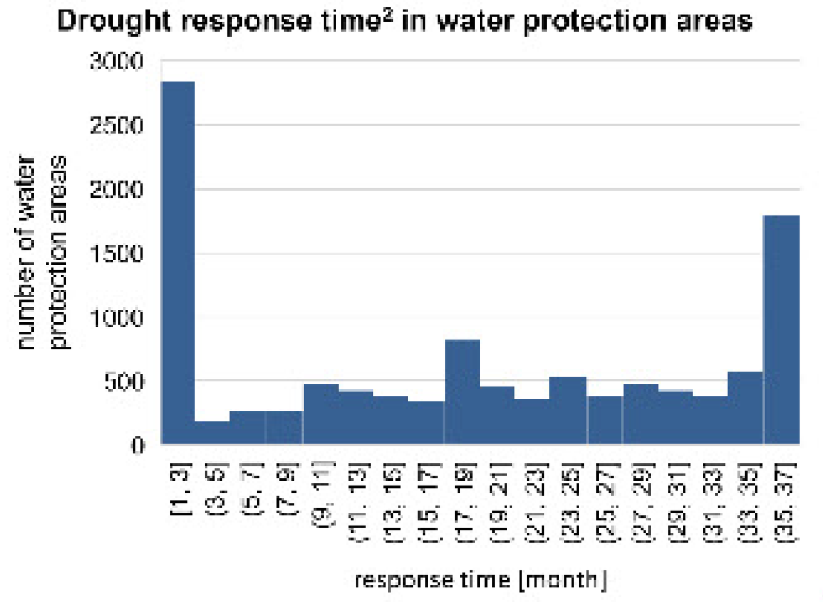
- Germany has 16 federal states.
- All federal states have their own state water law. There is no standard regulation for the designation of water protection areas.
- In our study we identified 11.406 drinking water protection and water abstraction areas, covering 14 % of the total area of Germany.











[1] Blickensdörfer et al. (2022)
[2] Hellwig et al. (2020)

Results: data perspective

- We identified 8 different drinking water situations in Germany.

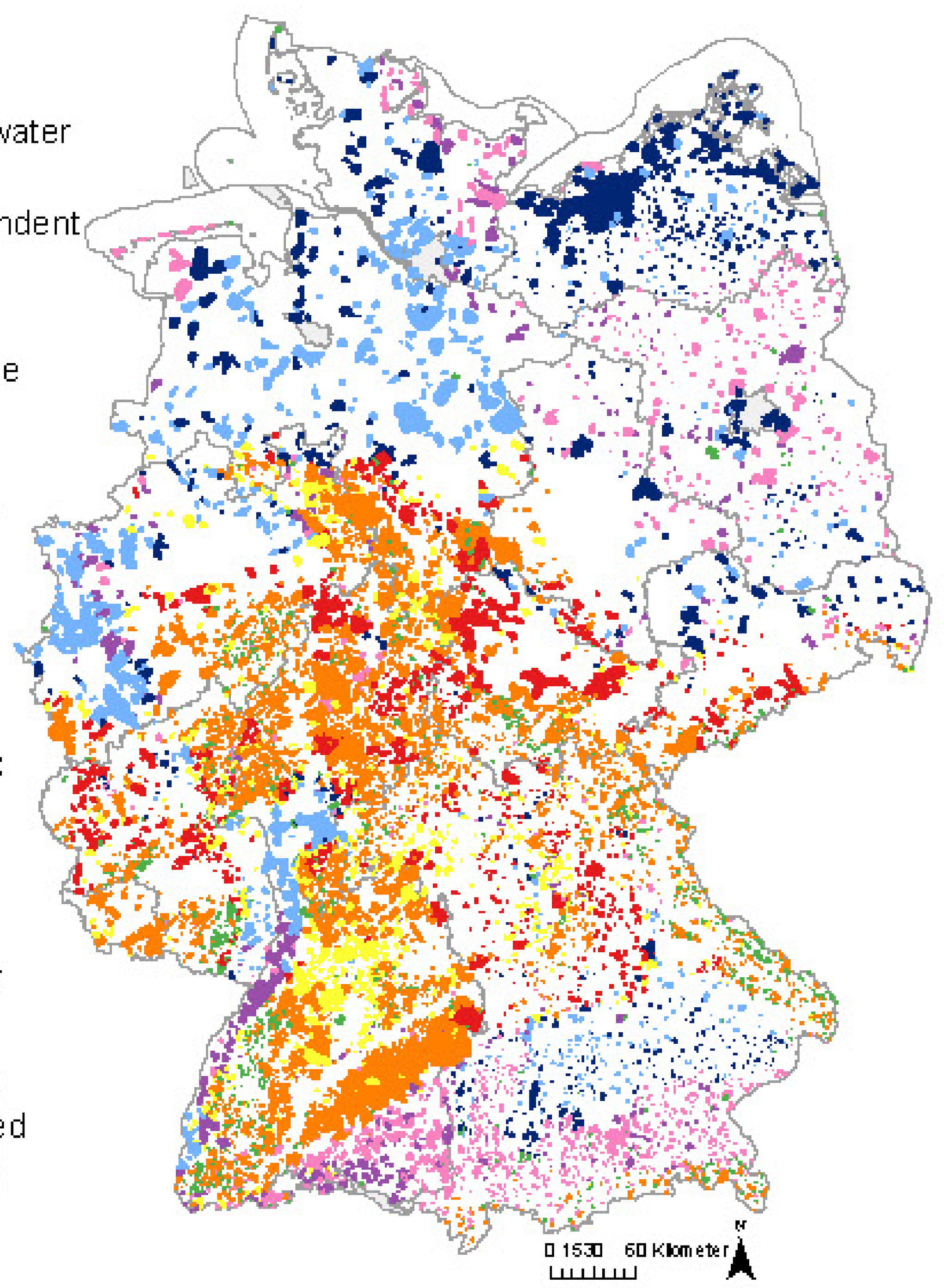
Cluster variables

Numerical variables:

- groundwater/spring water abstraction per year
- consumption-independent water fee
- population density
- groundwater recharge
- elevation range
- crop types (mean area share of maize, permanent grass-land and vegetables 2018-2021)

Categorical variables:

- land use type
- hydrogeology: porous aquifer or karst/fissured aquifer
- chemical status
- agricultural statistics: percentage of irrigated area (1-6 categories)



Cluster characteristics

+ (high) – (low)

Karst/fissured aquifer:

- Good chemical status:
  - drought response time -, groundwater recharge +, irrigation -
  - groundwater recharge -, irrigation +
  - groundwater recharge +
- Poor chemical status:
  - drought response time +, population density -, water costs +, irrigation -

Porous aquifer:

- Good chemical status:
  - drought response time -, groundwater recharge +
  - drought response time -, irrigation +
- Poor chemical status:
  - drought response time +, groundwater extraction +, groundwater recharge -, irrigation +
  - drought response time +, water costs +, elevation range -, irrigation -

Outlook

- Statistical model for characterizing clusters
- Regression analysis to identify main stress factors
- Building on this study with model developments in the "LURCH-StressRes" project, we later aim to develop transferable stress tests for the identified typical situations across Germany to inform adaptation and best practices for achieving sustainable nationwide drinking water management

LURCH Grundwasser nachhaltig bewirtschaften
stress RES
FONA Forschung für Nachhaltigkeit
Bundesministerium für Bildung und Forschung

Chair of Environmental Hydrological Systems, University of Freiburg
www.hydro.uni-freiburg.de
universität freiburg

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