International Water Research Alliance Saxony

# APPROACHES FOR DEALING WITH VARIOUS ASPECTS OF VAGUENESS IN WATER RESOURCES ASSESSMENT: A CASE STUDY APPLICATION IN OMAN


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## 1 Motivation & Objectives

A sound water resources assessment is an important component in the context of IWRM. However, in semi-arid regions performing a water resources assessment generally encounters a considerable vagueness as regards surface and subsurface hydrologic and geomorphologic data.

Fuzzy theory provides approaches for adequately handling such kind of vagueness. Within the BMBF-funded research project IWAS Middle East (Oman), an innovative fuzzy framework for consideration of vagueness in terms of spatial extent of recharge areas and spatially distributed recharge in a partly karstified mountain range was developed and applied to the pilot study area (see fig. 1). The results can be used as an upper boundary for groundwater modelling of the alluvial aquifer on the Batinah coastal plain.

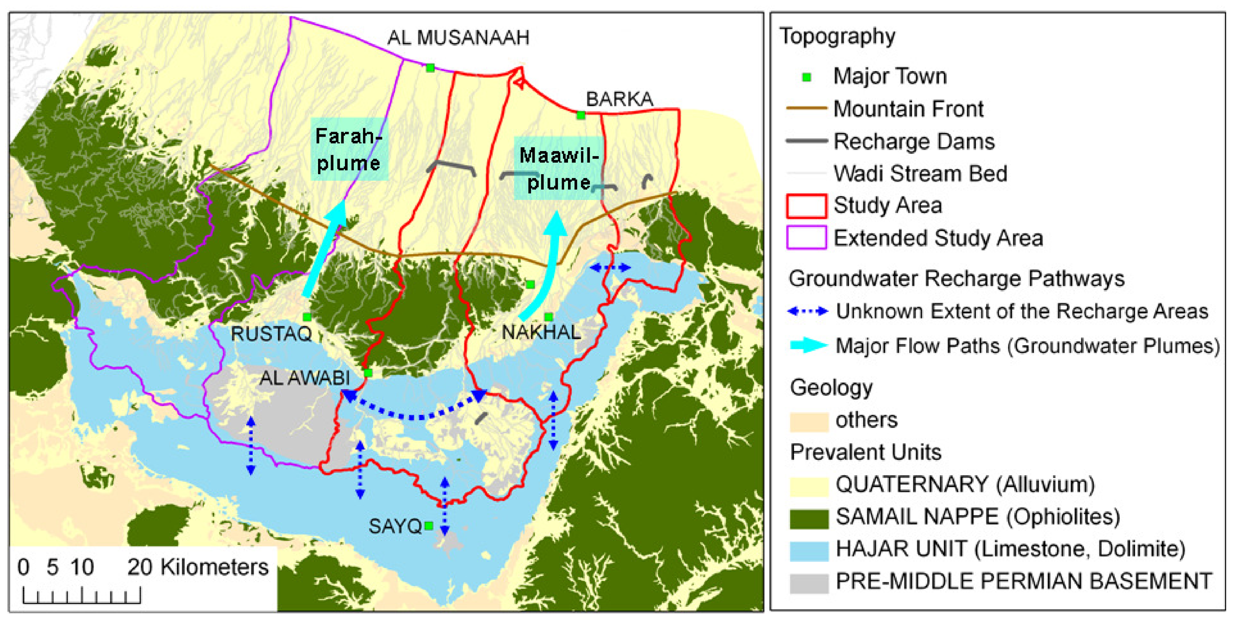

Fig. 1: Pilot Study Area – Geology and assumptions on recharge areas based on isotope studies

### Sources of Vagueness

- Extent of Recharge Areas
- Recharge Rates
- Accuracy of Rainfall Data
  - Measurement Errors
  - Probability Distribution of Future Climate Scenarios

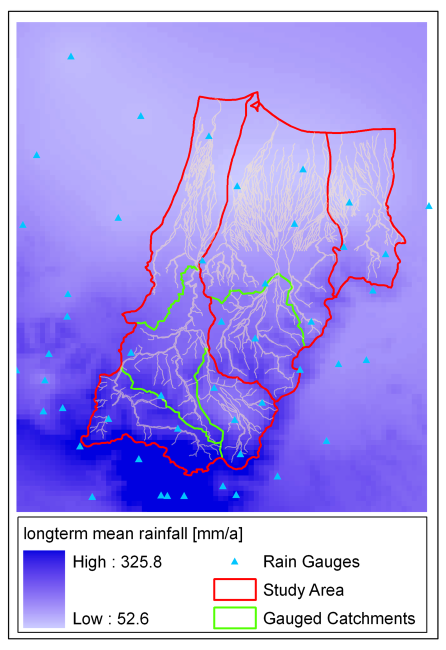

Fig. 2: Rainfall – monitoring network and longterm mean values

## 2 Methodology

The approach uses, on the one hand, fuzzy regions to describe the potential albeit unknown extent of the actual recharge areas according to Gerner & Schmitz (2011) (fig. 3). In doing so, qualitative expert knowledge (e.g. based on isotope studies) can be transformed into quantitative conclusions. These are related to certain $\alpha$-cuts, i.e. discrete areas with degrees of membership $\mu \geq \alpha$-cut-level.

On the other hand, fuzzy arithmetics is used for raster based estimates of groundwater recharge under consideration of vagueness in input data (rainfall) and recharge rates (fig. 4). In this case, the latter are based on the APLIS method for groundwater recharge assessment in carbonate aquifers (Andreo et al., 2008). However, alternative models are generally feasible as well.

### Vagueness in Spatial Extent of recharge areas using Fuzzy Regions

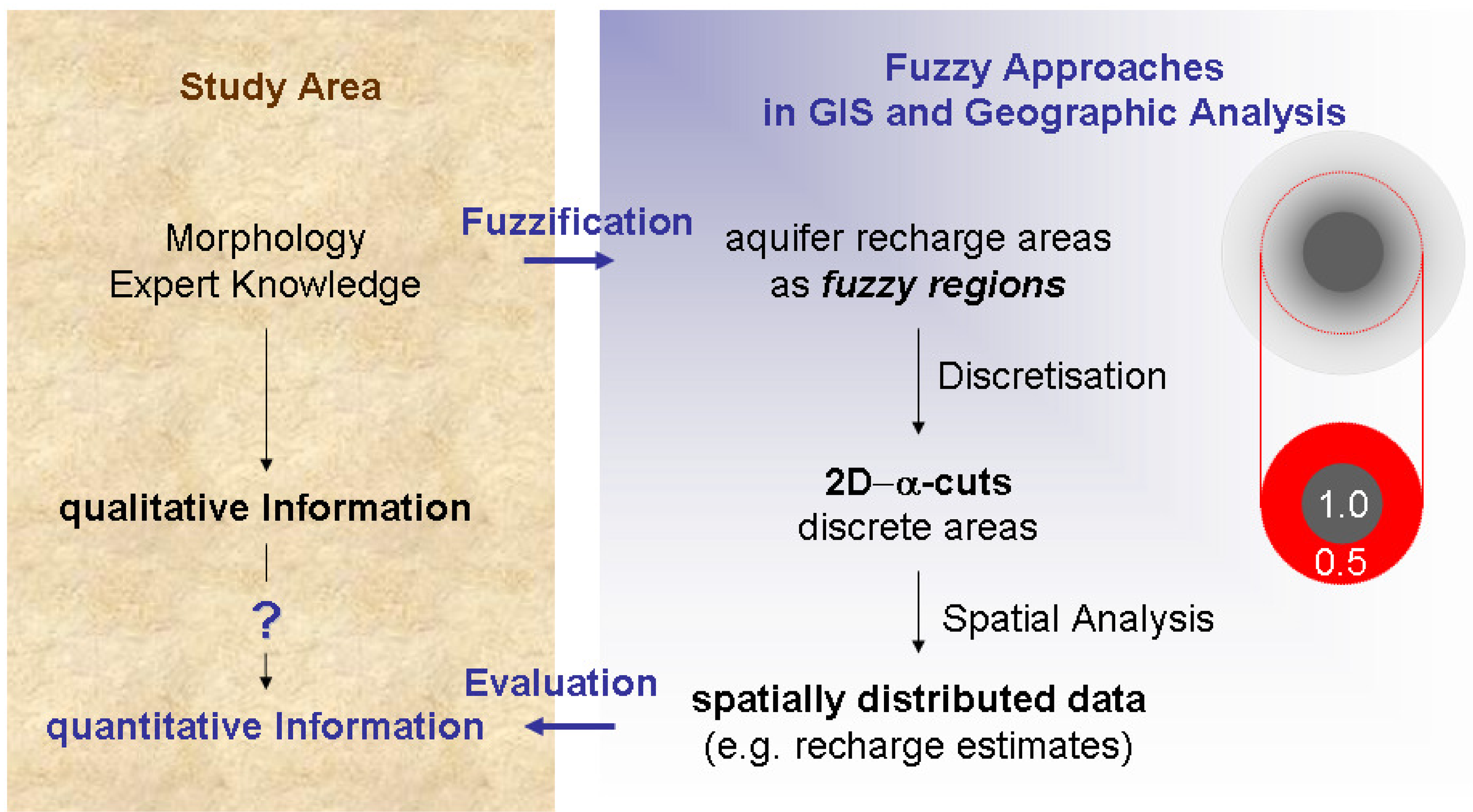

Fig. 3: The concept of fuzzy recharge areas (Gerner & Schmitz, 2011)

### Vagueness in Recharge Estimates using Fuzzy Arithmetics

Tab. 1: Raster-based recharge estimates based on APLIS (Andreo et al., 2008) under consideration of vagueness by use of fuzzy arithmetics

| Layer Precipitation | Data Content | Handling |
|---|---|---|
| (longterm mean) annual values | 1.observed data incl. consideration of measurement errors<br>2.scenario data (e.g. climate scenarios or stochastical simulation) | 1.Trapezoidal membership function (MF) – covering the observed (or interpolated) value and potential measurement errors<br>2.Probability Distribution of rainfall as fuzzy MF |
| **APLIS Method for Recharge Estimates in Carbonate Aquifers** (Andreo et al., 2008)<br>based on classification of geomorphologic variables according to the APLIS-rating<br>APLIS-Index of Recharge: Annual Recharge R = (A + P + 3*L + 2*I + S) / 0.9 [%] | | |
| **Layer** | **Data Content** | **Handling** |
| A – Alitude | non-ambiguous – exact classification based on DEM | crisp values (converted to MF) |
| P - Slope | | |
| L – Lithology | classification of limestone areas (degree of karstification) ambiguous | Trapezoidal membership functions – covering the potential ranges according to the APLIS rating |
| I – InfiltrationLandforms | | |
| S – Soils | may be ambiguous | |
| R_%: Recharge Rate [%] | Overlay of input parameters according to the APLIS-Index | results of fuzzy arithmetical operations |
| R_vol: Recharge Volume | Precipitation * R_% | |

## 3 Exemplary Application

Exemplarily, the approach is applied to the to the pilot study area in the Batinah-Region (Sultanate of Oman), which is located about 50 km west to the capital Muscat. Figure 5 shows the recharge calculation for a single raster cell. The Aggregation is, in the end, a loop over all raster cells of the actual $\alpha$-cut of the recharge areas. It results in fuzzy sets of recharge for single $\alpha$-cuts as shown in fig.6.

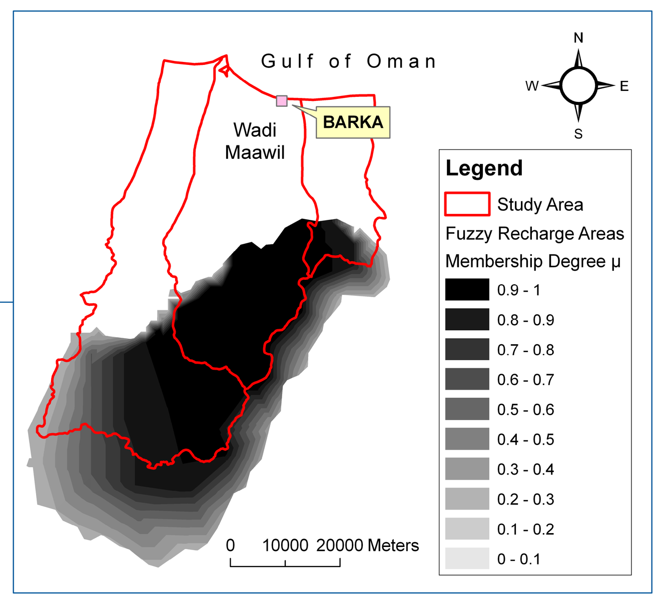

Fig. 4: **Fuzzy recharge areas** for the Maawil-plume

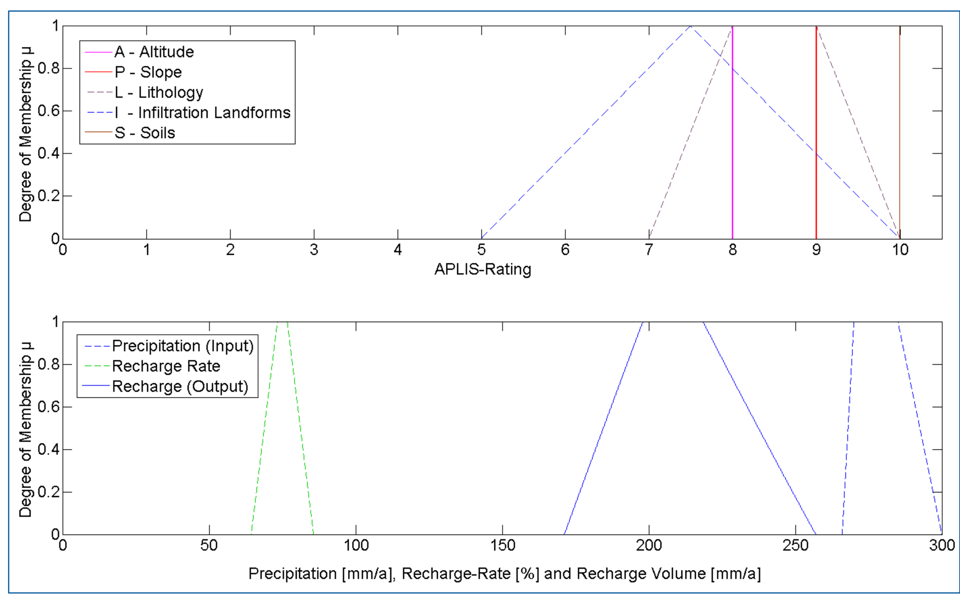

Fig. 5: **Recharge calculation** for a single raster cell

**Aggregation** using Fuzzy Arithmetics

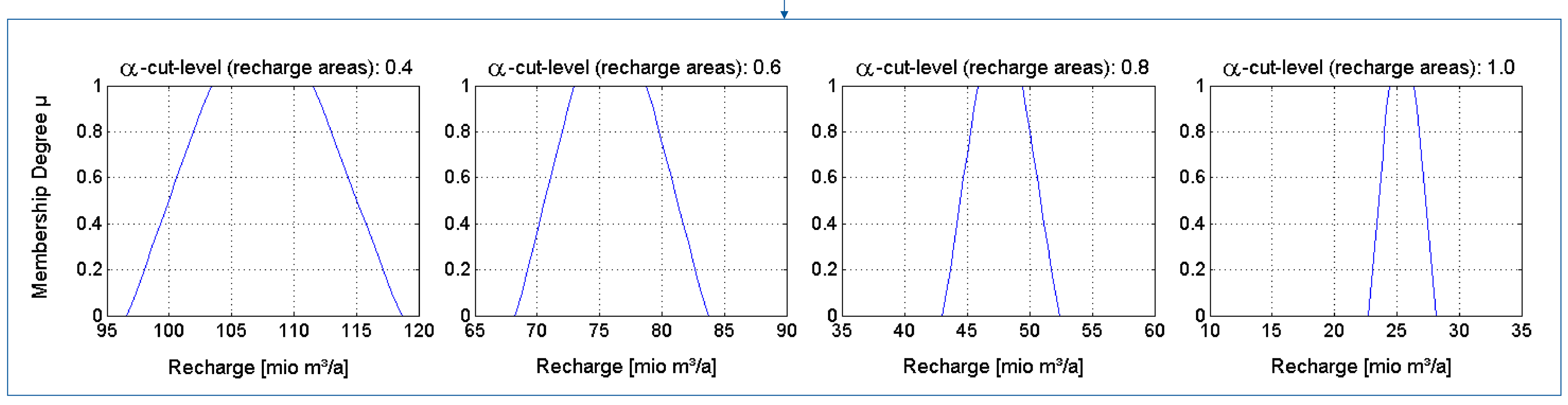

Fig. 6: **Fuzzy sets of recharge** related to $\alpha$-cuts of the fuzzy recharge areas

## 4 Conclusions

The combination of fuzzy recharge areas and fuzzy based application of a regionalisation approach provides an efficient approach for quantification of potential recharge under consideration of vagueness. The results are used as input for water balance calculations or as an upper boundary condition for groundwater modelling of the coastal aquifer, respectively. Thereby, the $\alpha$-cut-levels can be used as a sort of model parameter. Besides, expert knowledge on the study area (e.g. geology or results of isotope studies) is useful to set reasonable limits to the considered $\alpha$-cut-levels.

The APLIS-approach fits well in this framework. However, depending on objectives or available data and modelling tools, the use of alternative approaches within this framework is generally feasible. Beyond, temporal aspects (i.e. time lags between rainfall input and groundwater response) have to be considered in future as well.

### References


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