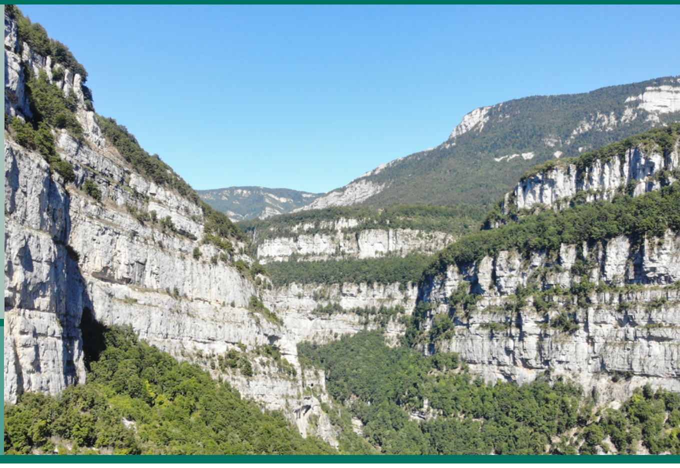

MedWater

Calculating groundwater stress of Mediterranean karst aquifers and estimating their vulnerability to climate change on a global scale

Key findings

- We calculate a Groundwater Stress Index (GSI) for 133 karst aquifers with Mediterranean climates and assess their vulnerability to climate change.
- The results indicate increased groundwater stress in southern Spain and northwest Africa, parts of Greece, and the Middle East, while many aquifers on the European Mediterranean coast show relatively low stress.
- Different aquifer groups show very similar trends of higher GSI values with temperature increase and precipitation decrease with varying magnitude.

Motivation

Humans and ecosystems around the world rely on groundwater from karst aquifers. They are particularly abundant in the Mediterranean region. Due to complex karst structures, these aquifers have high infiltration capacities as well as high hydraulic conductivities, which makes them vulnerable to pollution and, as their prediction and management are complicated, overexploitation. Currently, many aquifers are under stress due to rising water demands. Available groundwater resources may decline further, as climate change could strongly decrease natural recharge. To have a quantitative indication of the current and future state of these critical groundwater resources, we assessed the current level of quantitative groundwater stress of karst aquifers with Mediterranean climates and investigated how similar aquifer types differ in terms of groundwater stress with varying temperature and precipitation. The idea is that comparable aquifers with currently higher temperature or less precipitation may serve as a projection for how other aquifers' stress could increase in the future, thus, how vulnerable they are to climate change.

Methodology

For the selection of Mediterranean karst aquifers, we overlaid the World Karst Aquifer Map with Mediterranean climate zones (Csa, Csb, Csc) after Köppen-Geiger (Beck et al., 2018). To increase the level of detail, the original karst aquifers were subdivided using HydroBASINS-data. Based on the condition that >50% of their area is assigned to any of the three Mediterranean climate types, we identified 179 karst aquifers or sub-areas. For the selected aquifers, we calculated a Groundwater Stress Index (GSI) based on seven indicators. Hydrogeological indicators – groundwater recharge (I1), storage (I2), and abstractions (I3) – were provided by outputs form the global freshwater model WaterGAP (2.2d). We included two hydrological indicators based on ERA5 data: Runoff relative to average precipitation (I4) and the climatic water balance (precipitation minus potential evapotranspiration). I6 measures the area irrigated with

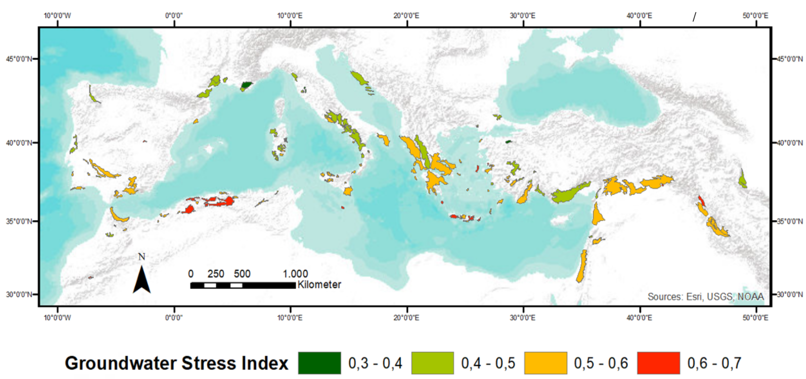

Figure 1: Groundwater Stress Index for 133 Mediterranean karst aquifers (focus on Mediterranean Sea); 0 = no water stress, 1 = extreme water stress

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Groundwater stress

Groundwater stress is commonly interpretated as the imbalance between natural recharge and abstractions for human use. Recent studies (e.g., de Graaf et al., 2019) showed the importance of adding environmental flow requirements to this equation. Excarcabated by population growth and climate change, groundwater ressources are under extreme pressure: Gleeson et al. (2012) calculated that the global groundwater footprint ("the area required to sustain groundwater use and groundwater-dependent ecosystems") is 3.5 times the actual area of aquifers.

groundwater expressed as percentage of total area equipped for irrigation (FAO AQUASTAT). Finally, I7 identifies groundwater-dependent ecosystems, based on natural areas that maintain a relatively constant amount of green vegetation (high NDVI; MOD13Q1 data) during dry periods.

Results

Indicator values were spatially and temporally averaged to describe a recent trend on aquifer level and normalized to range between 0 (no water stress) and 1 (extreme water stress). For index composition, we gave each indicator an equal weight, although groundwater storage was excluded because of high correlation with groundwater recharge. Due to incomplete data for individual indicators, we could calculate a Groundwater Stress Index (GSI) for 133 aquifers. The result is shown in Figure 1 for the Mediterranean, indicating increased groundwater stress in southern Spain and northwest Africa, parts of Greece, and the Middle East. In comparison, many aquifers on the European Mediterranean coast show relatively low groundwater stress. The aquifers were afterwards grouped based on similarities in two classification parameters: degree of karstification (terrain was used as a proxy) and land cover. With three classes each, we built 9 aquifer groups. For each group, we plotted calculated GSI values with the aquifers' average annual temperature and precipitation (ERA5 data). We then assessed the difference in groundwater stress accompanied by altered climatic factors (i.e., the vulnerability to climate change). The results are summarized in Figure 2. In general, all 9 groups show very similar trends of higher GSI values with temperature increase and precipitation decrease with varying magnitude.

Application

Our approach mimics the effect of climate change on groundwater stress relying on present-day observed conditions. The methodology's simplicity is its greatest strength and limitation, as information is unavoidably lost through temporal and spatial data aggregation. Furthermore, some of the defined aquifer groups did not have enough members to be a representative sample. This had a strong effect on the identified vulnerability trends, showing the steepest slopes in the groups with the fewest members. This could be mitigated by adding additional climate zones into the analysis, considering that, as shown by Beck et al. (2018), Mediterranean climate zones are likely to expand or shift until the end of the century.

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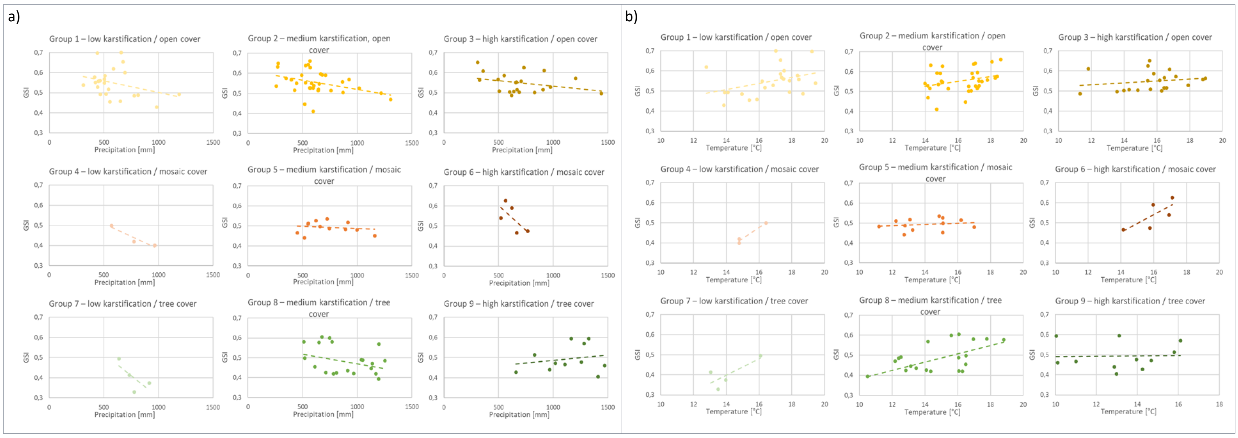

Figure 2: Relationship between groundwater stress (GSI) and a) average sum of annual precipitation (2000-2019) and b) average annual temperature (2000-2019) for 9 aquifer groups, based on similar karstification and land cover

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