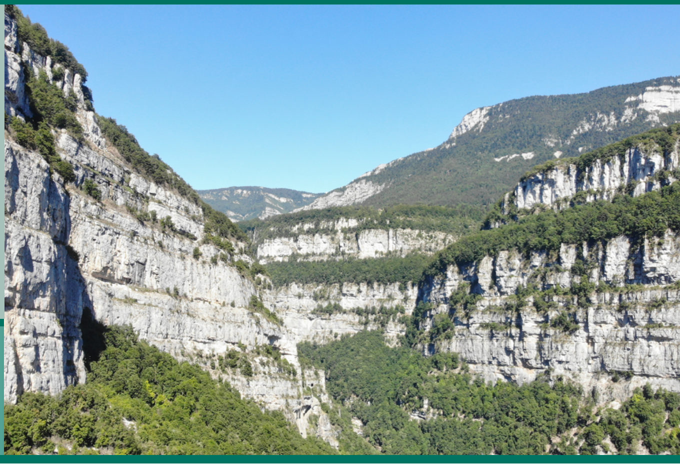

Calculating groundwater stress and climate change-induced vulnerability of karst aquifers on a global scale

Key findings

- We calculate a Groundwater Stress Index (GSI) and assess vulnerability to climate change for 356 karst aquifers with Mediterranean climates.
- GSI is calculated from six indicators: groundwater recharge, storage, and abstractions (I1-3), climatic water balance (I4), water-intensity of crops (I5), and groundwater-dependent ecosystems (I6).
- As calculations are still underway, this note focusses on methodology. Overall, we expect high vulnerabilities to climate change, as 52 out of 356 aquifers are projected to move into more extreme arid climate zones by 2100.

Motivation

Humans and ecosystems around the world rely on groundwater from karst aquifers. 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 prediction and management are complicated, overexploitation. As populations are growing and demand rises, many aquifers are now under stress. Available groundwater resources may decline further, as climate change is expected to decrease natural recharge. Here, we assess the current level of groundwater stress in karst aquifers with Mediterranean climates and their vulnerability (defined as the change in groundwater stress) to expected changes in temperature and precipitation on the global scale. For aquifers that seem particularly threatened, our goal is to develop recommendations for sustainable management. As this sub-project of the MedWater initiative is still in progress, this technical note focuses on methodology and will be updated as soon as results are available.

Methodology

For the selection of karst aquifers with Mediterranean climates, we overlaid the World Karst Aquifer Map (WOKAM) with Mediterranean climates (Csa, Csb, Csc) after Köppen-Geiger (Beck et al., 2018). This resulted in 356 aquifers. Figure 1 illustrates the workflow of calculating a Groundwater Stress Index (GSI) and assessing vulnerability to climate change. The GSI is based on six indicators. Hydrogeological indicators (I1-3) – groundwater recharge, storage, and abstractions – were provided by outputs form the global freshwater model WaterGAP (version 2.2d). I4 considers the climatic water balance (difference between precipitation and potential evapotranspiration; ERA5 data). To assess the water-intensity of crop production (considering agriculture as the commonly most

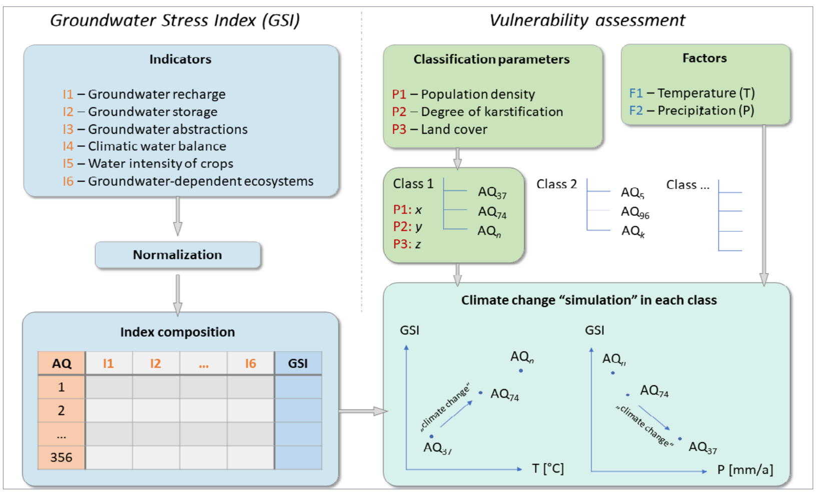

Figure 1: Calculating a Groundwater Stress Index (GSI) for 356 karst aquifers (AQ) with Mediterranean climates and assessing AQ vulnerability to climate change

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MedWater

water-intensive sector), I5 determines levels of evapotranspiration for rainfed cropland (ERA5 data). Finally, a global workflow was implemented to quantify groundwater-dependent ecosystems (I6): These were identified assuming that areas which maintain a constant amount of green vegetation (high NDVI; MOD13Q1 data) during dry periods are likely to have access to groundwater. Each indicator is spatially and temporally averaged to describe a recent trend on aquifer level, resulting in one complex attribute table for the 356 aquifers. Indicator values are normalized to take on numbers between 0 (*no water stress*) and 1 (*extreme water stress*). An average of all indicator values is built to describe current groundwater stress. Aquifers are then grouped based on similarities in three classification parameters (P1-3) – population density, degree of karstification, and land cover. For each group, we plot calculated GSI values with temperature and precipitation data (ERA5). Based on SSP scenarios, we identify aquifers (e.g., AQ_{74} in Figure 1) that mimic future climate conditions for aquifers with comparatively lower temperatures and higher precipitation (e.g., AQ_{37}). We then measure the difference in groundwater stress due to altered climatic factors. This change is interpreted as vulnerability to climate change. Thus, we obtain a "model" result for a particular climate scenario, without having applied an actual model.

Application

We are yet to calculate indices and derive vulnerabilities for the selected aquifers. We expect both to be high, based on predictions by Beck et al. (2018) regarding future climate zone shifts: Out of the 356 aquifers, 52 will have moved to more extreme arid climate zones by 2100 (Figure 2). Our approach mimics the effect of climate change on groundwater stress relying on present-day observed conditions. Its simplicity is its greatest strength and limitation, as information will unavoidably be lost through temporal and spatial data aggregation. Furthermore, although we compare aquifers that are most similar in terms of population density, karstification, and land cover, our approach cannot account for changes in these parameters. As population density rises in most areas of the world, predicted changes in groundwater stress are likely underestimates. Results will be visualized in vulnerability maps that may serve as an "early-warning system". For particularly threatened aquifers, we will derive recommendations for more sustainable management by suggesting strategies to lower groundwater stress. This is done by taking a closer look at the aquifer's indicator values and identifying factors that currently contribute the most to groundwater stress.

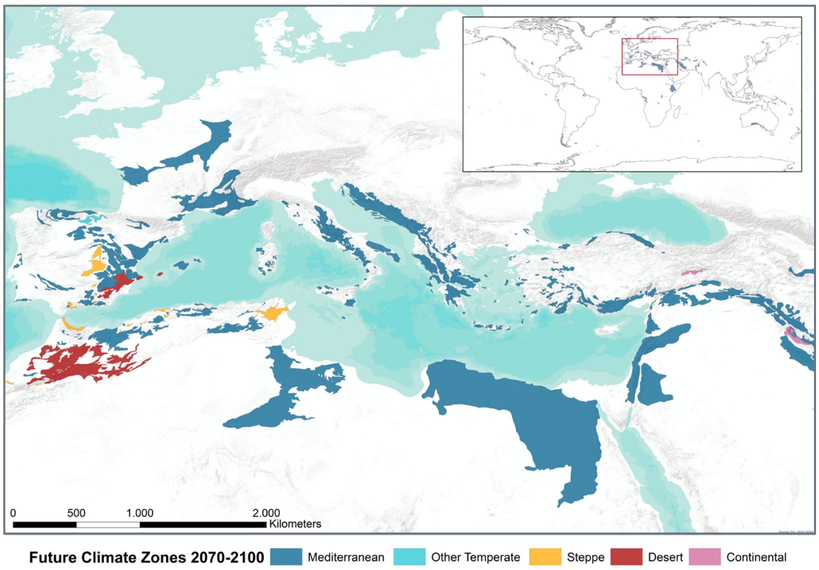

Figure 2: Shifts in climate zone classification for currently Mediterranean karst aquifers until 2100, as predicted by Beck et al. (2018)

Groundwater stress

Groundwater stress is commonly interpreted 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.

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