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Groundwater salinization in coastal areas worldwide: effects of geological heterogeneity on onshore and offshore fresh groundwater reserves

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In the near future, fresh groundwater reserves in the coastal zone are shrinking at a larger pace due to aquifer overexploitation triggered by growing urbanization and population numbers and/or sea-level rise (up to 1m or even 2m by the end of the century). Therefore, it is crucial to fully comprehend and simulate the current fresh-saline groundwater distribution in the coastal zone and understand what will be the effects of future management and policy strategies on groundwater. To achieve that knowledge level, it is necessary to recognize the effects of the past sea level fluctuations as well as the influence of geological heterogeneity on the fresh-saline distribution. In this study, we combine geological and hydrogeological knowledge, global datasets on coastal segmentation and density-dependent groundwater flow modelling to estimate coastal onshore and offshore fresh groundwater reserves subject to geological heterogeneity (and its uncertainty).

First, we use a set of open source global datasets and geological concepts to deduce the composition of the unconsolidated sediment aquifer-aquitard systems by means of a sand/mud ratio representing the high and low permeable sediment layers, respectively. Then, the COSCAT classification (Coastal Segmentation and related catchments) linking inland river catchments (sediment source) with continental shelves (sediment sinks) is used to divide the global map into regions with identical geological conditions. Finally, we determine that the combination of sediment input, sediment type ratio and subsidence rate are the main factors that define the composition and structure of an aquifer-aquitard systems.

In the next stage we create a representative 2D vertical variable-density groundwater flow model perpendicular to the shoreline for each COSCAT region. This representative profile is constructed based on the average inland and offshore elevation, aquifer thickness at the coastline and inland extent of the coastal sediment plain of multiple individual 2D profiles located within each COSCAT region. These individual profiles are created every 5km along the coastline of each COSCAT region. Since the exact number and extent of low permeable aquitard layers is unknown for the majority of the world's coastal groundwater systems, we create a number of randomized Monte-Carlo geological profiles obeying the previously determined geological input factors (as described above).

By applying these geological profiles as input to the variable-density groundwater flow models (using the SEAWAT code), we are able to determine per COSCAT region: the presence of onshore and offshore fresh and brackish groundwater; the submarine groundwater discharge; and the estimate the time it takes for such a groundwater system with the associated geological profile to reach a flow equilibrium (we call it the characteristic time). Hence, we can also indicate areas with potential offshore fresh groundwater reserves to be exploited in the future and provide a time scale input for models to execute the regional and local paleo-geographic reconstruction of variable-density groundwater flow.