25th International Congress on Modelling and Simulation, Darwin, NT, Australia, 9 to 14 July 2023
mssanz.org.au/modsim2023

Modelling the impact of climate change on global groundwater temperatures

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Abstract: Groundwater plays a vital role in sustaining life on Earth. While most of the focus on groundwater relates to available volumes and pollution, groundwater temperatures play a crucial role in a range of processes, including aquatic biogeochemical processes, groundwater quality, and geothermal energy production. Groundwater temperature is also strongly linked to thermal refugia in rivers through groundwater discharge. Despite the broad range of processes that groundwater temperatures influence, the impact of surface warming on groundwater temperatures at different spatial and temporal scales remains unclear. This study presents global-scale simulations of current and projected groundwater temperatures. The study utilises modelling in three stages. (1) Global Climate Model outputs are used as drivers of groundwater warming. (2) These drivers are used as boundary conditions for conductive-1D analytical solutions/models of heat transport. Finally, (3) numerical heat and groundwater flow models are used to support the selection of the conduction-only model.

Our results show that global groundwater temperatures at the depth of the water table are projected to increase by an average of 1.7°C between 2000 and 2099 under the CMIP5 RCP 4.5 scenarios (3.3°C under CMIP5 RCP 8.5). The warming rates vary significantly across different regions due to the spatial variability in climate change, thermal properties of aquifers, and water table depth. The areas with the highest projected warming rates include central Russia, northern China, parts of North America, and the Amazon rainforest.

Our simulations also reveal the variability in the impact of climate change on subsurface temperatures to a depth of 100 m. The models show that shallow groundwater temperatures can vary significantly across seasons and locations, with seasonal variations ranging from little-to-no variation to more than 10°C in some areas. The impact of short-term weather conditions is more significant in the uppermost layers, while the long-term effect of climate change penetrates deeper into the subsurface, with observable temperature increases at >100 m below the land surface.

We estimated the accumulated energy absorbed by the terrestrial subsurface from the beginning of the industrial revolution to 2020 and projected the energy that will be accumulated by 2099. Our findings suggest that elevated groundwater temperatures could have negative impacts on water quality and on groundwater-fed thermal refugia. However, accumulated subsurface heat can provide a reliable energy source in many regions, where heat can be extracted through wells in productive aquifers. This recycled energy can provide a carbon-reduced heat source that will benefit from climate change.

Our study provides crucial insights into the response of groundwater to surface warming at a global scale. The results highlight the need for local-scale hydrogeology studies to better understand the variability in large-scale thermal changes in the subsurface. Our modelling approach can serve as a valuable tool for assessing the impact of climate change on groundwater resources and designing sustainable groundwater management strategies.

Keywords: *Groundwater, heat, temperature, global climate models, CMIP5, analytical modelling*