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Towards modelling the effects of groundwater-fed irrigation on the Ganges basin: incorporating 2D lateral groundwater flow and groundwater and surface water-fed irrigation in the VIC macroscale hydrological model

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Agricultural intensification in the Ganges basin since the mid-1960s has led to the increased use of surface water and groundwater-fed irrigation. To understand the dynamics and future evolution of such a human-influenced system, models are required that represent both interactions between physical processes and agricultural practice describing the source, quantity and timing of irrigation.
Here, we incorporated a (i) 2D lateral groundwater model, and (ii) flood irrigation into the VIC macroscale hydrological model, with the future aim of applying it to simulate the effects of agricultural practice, land use change, groundwater pumping, and surface water irrigation on ecological flows in the River Gandak and the wider Ganges.
We included the 2D lateral groundwater model within the image version of VIC 5, by modifying the boundary condition at the base of the soil column to simulate varying recharge rates as the groundwater table fluctuates, similarly to that of the previously developed SIMGM model. This recharge formulation is both a function of soil moisture and the depth to the groundwater table, and includes drainage by gravity and capillary rise. Saturated lateral groundwater flow was simulated using a one layer 2D groundwater model. Replacing VIC's baseflow formulation, groundwater discharge to the land surface is described either through river baseflow, or through capillary rise of groundwater into the soil column and increased evapotranspiration and/or runoff.
The VIC model was further modified to incorporate groundwater and surface water-fed irrigation. In the Ganges basin, crops are cultivated over Kharif and Rabi seasons which were modelled separately. The irrigation scheme used is flood irrigation, and for crops that are submerged, such as rice, paddy formulation was added.
The VIC-groundwater model was applied to an idealised and homogenous system based on the upper Ganges catchment. We investigated the role of the groundwater discharge, aquifer properties and grid size, in controlling spatial variability in water table depth, groundwater recharge, discharge and evapotranspiration. Feedbacks between depth to the groundwater table and the land surface fluxes increase for aquifers with a high aquifer hydraulic conductivity, modelled on a fine grid resolution. Comparing models with different grid sizes and aquifer properties, we find that lateral groundwater flow and depth to the water table are especially dependent on grid size for aquifers with a high hydraulic conductivity, however less so for lower hydraulic conductivity. Therefore, it will be important when simulating groundwater abstraction and irrigation in aquifers with a high hydraulic conductivity, such as the Ganges base, to use a fine spatial model grid.
The next objective is to combine the VIC-groundwater and the VIC-irrigation version, and drive it with a farmer behaviour model. This integrated model will be applied to study the effect of irrigation on the water and energy balances over Ganges Basin.