Geophysical Research Abstracts
Vol. 20, EGU2018-18334, 2018
EGU General Assembly 2018

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

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People have had a profound effect on the hydrological system of the Ganges basin. Agricultural intensification since the mid-1960s has led to the increased use of surface water and groundwater-fed irrigation, and urbanisation has modified infiltration and recharge to groundwater. To understand the dynamics and future evolution of basin-scale hydrological systems, models are required that represent the interactions and feedbacks between human and natural processes, for example the impact of groundwater-fed irrigation on depleting aquifer levels, and vice versa.

Currently, most macro-scale models have limitations as the land surface hydrology is traditionally characterised as one-dimensional in the vertical direction, partitioned into large, thin cells, and run-off routing is performed a posteriori. In particular, there are limitations with regard to groundwater, which is often only represented through a baseflow component from the bottom layer of the soil column, for example as a function of relative moisture; this is the case for the macro-scale hydrological model VIC. Hence, the baseflow component does not relate to the depth of the groundwater table, and groundwater cannot be spatially distributed between the cells. We addressed this by modifying VIC, which has been recently improved with HPC parallelization strategy using MPI, to include a 2D lateral groundwater flow module (ambhasGW) 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.

Within the image version of VIC 5, we modified 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 can be either upward or downward. After removing VIC's baseflow function, we then incorporated a 2D groundwater model to simulate saturated groundwater flow and the groundwater table, which is linked to the land surface to simulate baseflow to rivers. The groundwater table depth and baseflow are fed back from the groundwater model into VIC after each time step and the updated groundwater table depth is used for the recharge calculation at the next time step. The model is applied to an idealised system based on the upper Ganges catchment to investigate at what scale it is important to represent lateral groundwater flow as aquifer diffusivity varies.

Finally, we summarise the next objective: to incorporate an irrigation demand module into VIC, representing farmer irrigation practices, that couples water demand, and surface water and groundwater use, with soil water, surface water and groundwater states.