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Spatial and Temporal Variability of Groundwater Recharge in Changing Semiarid Dune Environments

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Groundwater recharge (GWR) is one of the major factors controlling water resources in semiarid and arid regions. This time-space-dependent flux is needed for groundwater modeling, analysis of climate change impacts, and water resources management. Typically, climate changes are studied on multi-decadal to centennial time scales, but travel times of soil moisture across the vadose zone vary broadly and may exceed multi-centennial periods in semiarid and arid environments. For given climatic conditions on the land surface, we evaluate travel times in the vadose zone and compare with times scales of climate change studies. This comparison defines the land surface areas contributing to GWR changes where travel times are shorter than times scales of climate change studies. In areas with travel times longer than climate change time scales, GWR remains unchanged over the considered period of water resources management. Such analysis allows for separation of the effect of land surface topography and vadose zone thickness from that of spatial and temporal variations in climate.

Our simple travel time estimates are based on the velocity of a pressure pulse from the land surface, equivalent to a kinematic wave approximation of Richards' equation. The underlying assumptions of a unit hydraulic head gradient and relatively small magnitude of changes to upper boundary flux, caused by slow climate changes, are supported by observations in the High Plains aquifer region, USA. The input data include DEMs of land surface and groundwater table elevations, future projections of hydroclimatic variables, precipitation and evapotranspiration (WCRP-CMIP3 with hydrology VIC model outputs), and estimates of hydraulic conductivity from pedotransfer functions. Future GWR rates are estimated in four steps: GIS analysis of vadose zone thickness using difference in DEMs; evaluation of deep drainage rates based on difference between precipitation and evapotranspiration rates (PRISM and MODIS, respectively); calculation of travel times of moisture across the vadose zone and GIS mapping; and inference of time-referenced GWR map. This methodology is applicable to semiarid and arid regions, where overland flow can be neglected and actual evapotranspiration and precipitation data for current and future conditions are available. A study of the Nebraska Sand Hills, USA, the largest vegetated dune field in the Western Hemisphere of area 58,000 km2, provides analysis of spatial and temporal aspects of GWR with consideration of future climate changes.