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Towards large-scale characterization of subsurface vulnerability due to agrochemical pollutants across Europe

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Subsurface contamination due to diffuse agrochemical pollutants such as pesticides, herbicides, excess nutrients (N, P, K) is a widespread problem in a cultivated areas across Europe. Large-scale spatio-temporal patterns emerge from interplay of heterogeneous and dynamic hydrologic and biogeochemical processes in the near-surface critical zone (top one-meter of root-zone soil layer) which contribute to landscape filtering of stochastic hydro-climatic forcing. Such outcomes are of interest in characterizing the transient behavior of transport-reaction dynamics operating in the root-zone soil compartment which drive recharge and solute loads to sub-surface compartments (shallow groundwater and eventually to river networks). Here, using novel state-of-the art daily-scale hydrologic simulations (mHM; around 5x5 km grid) driven by observed hydro-climatic forcing, we demonstrate the strong spatio-temporal heterogeneity of hydrologic transport at the continental scale – reflected in time-varying travel time distributions (TTDs) – primarily controlled by the prevailing hydro-climatic gradient of aridity index across Europe. We link the space-time dynamics of TTDs – representing the intrinsic vulnerability of hydrologic system - to spatial heterogeneity and temporal fluctuations of biogeochemical turnover time-scales to provide a parsimonious biogeochemical model for identifying the extent of subsurface contamination due to diffuse (agrochemical) pollutants. Our assessment results show a large increase in the extent of vulnerable areas that are prone to subsurface nitrate leaching across Europe, compared to current (static) indices based approaches. We highlight the implications of improved vulnerability maps to better support agricultural subsidies and nitrate management across Europe.