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Geochemical interaction of antibiotics at agricultural soil-irrigation water matrix interface in varying environmental conditions

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Antibiotics play a vital role in controlling bacterial infections in both human and veterinary medicine and are widely used worldwide. However, due to incomplete metabolism, antibiotics are frequently discharged into water systems, contaminating rivers, lakes, and other water bodies. Antibiotics are transported via surface runoff, leaching and percolation to groundwater, and adsorption–desorption processes in soils. The accumulation of antibiotics in the environment leads to antimicrobial resistance (AMR) which can spread globally and threaten our health. Ciprofloxacin is widely used antibiotics in human and veterinary medicine and consistently detected in all sampling sites due to higher stability and slow degradation. Studies have investigated the presence of CPX not only in soils and groundwater near Indian river basins, but also its uptake by plants at higher exposure concentrations.

To understand the geochemical fate of Ciprofloxacin under varying physicochemical conditions (pH, Temp, Water matrices) and role of organic matter in controlling Fate, transport and degradation pathways of antibiotics. Batch and column studies were performed to insight into the thermodynamic behaviour, kinetic processes, and underlying adsorption mechanisms.

Results indicate that black soil exhibits the highest retention capacity (q ~ 20,000 mg/kg), followed by alluvial soil (~12000 mg/kg) and red soil (~7000 mg/kg), consistently across all studied parameters. Black and alluvial soils followed the Freundlich isotherm model, whereas red soil exhibit the Langmuir isotherm. Kinetic experiments revealed that black soil rapidly retained ciprofloxacin, achieving near-complete removal within 10 minutes. Water matrices significantly influenced adsorption, with the highest capacity observed in rainwater, followed by river water, groundwater, and 0.01 M $CaCl_2$ solution. pH significantly influenced adsorption, with the highest uptake under slightly acidic conditions and a progressive decrease as alkalinity increased. FTIR peak shifts in –OH/–NH, C=O, and C–F regions confirm ciprofloxacin adsorption via hydrogen bonding and surface complexation, with stronger interactions in black and alluvial soils.