Title: GeoDetector-based assessment of DOC-metal risk hotspots and LULC-climate projections in the Upper Meghna River system

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Abstract: Dissolved organic carbon (DOC) plays a pivotal role in regulating the mobility and bioavailability of trace metals in freshwater systems, yet its interactions with land-use and climate drivers remain poorly constrained in South Asian river basins. This study identifies key risk thresholds and examines their spatial and future implications for DOC-metal interactions in the Upper Meghna River, Bangladesh. Using the Geographical Detector Method (GDM), spatial hotspot statistics (Getis-Ord Gi*, Local Moran's I), interpretable machine learning (ICE, ALE, LIME), and Bayesian Belief Networks (BBN), DOC enrichment above ~6 mg L^{-1} and built-up land cover exceeding ~25% are shown to consistently elevate the probability of high-risk conditions, particularly for Pb, Cr, and Ni. These threshold exceedances are spatially concentrated near industrial areas, market centers, and launch terminals, where multiple analytical frameworks converge on similar hotspot signals across 23 monitoring stations. Future land-use/land-cover projections and CMIP6 climate scenarios (SSP2-4.5 and SSP5-8.5) indicate that hotspot extents may expand by 10-15% by 2050, driven by continued urbanization and intensified monsoon processes. The findings support the adoption of threshold-based monitoring, spatially targeted mitigation at key anthropogenic nodes, and nature-based solutions such as riparian buffers. Incorporating DOC-metal thresholds into India-Bangladesh cooperative frameworks could strengthen evidence-based transboundary river governance.

Keywords: Climate scenarios and river management; Dissolved organic carbon (DOC); GeoDetector and machine learning;

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