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Why do identical adsorbents behave differently across diverse hydrochemical regions in the context of fluoride removal?

MR. AKSHAY KASHYAP[1,2], LAURA A. RICHARDS[2], SUZIE M. REICHMAN[1], KATHRYN A. MUMFORD[1] AND MEENAKSHI ARORA[1]

[1]The University of Melbourne
[2]The University of Manchester

Fluoride adsorption performance in groundwater treatment systems varies widely across sites, even when identical adsorbents are deployed under comparable operating conditions. This suggests that hydrogeochemistry, represented in part by hydrochemical facies of differing composition may impact fluoride (and potentially other contaminants) removal performance [1,2]. Despite extensive laboratory evaluations of adsorbents, most studies rely on simplified matrices (deionized water) that do not necessarily represent the chemical buffering and competitive environments characteristic of natural groundwater systems [4,5]. In practice, many community-scale defluoridation units (as observed in West Bengal, India) underperform, possibly due to an interplay of hydrochemical variability, competing ions, inadequate system characterization, and operational inconsistencies [6]. In this study, we prepared five simplified matrices of major groundwater types (SW-1 to SW-5) to demonstrate that identical adsorbents exhibit statistically significant differences in fluoride removal across multiple facies, confirming hydrochemical facies as a key factor influencing fluoride removal performance (Figure 1a). One-way ANOVA confirmed a statistically significant effect of hydrochemical facies on fluoride removal performance ($p<0.05$). $C_{final}/C_{initial}$ ratios of fluoride varied across facies, with water representing Na-HCO_3 facies (SW-2) exhibiting the highest residual fraction of fluoride (~0.67), indicating strongest inhibition, whereas chloride-dominated synthetic water (SW-4) showed lowest residual fractions (~0.37) of fluoride (Figure 1b). Post-hoc comparisons identified bicarbonate-rich systems as significantly different from low-competition facies (e.g. chloride-dominated), confirming facies-dependent adsorption behaviour for the selected adsorbent. These results suggest rethinking the conventional practice of ranking adsorbents independent of geochemical context and incorporating hydrochemical variations during adsorbent selection for defluoridation.

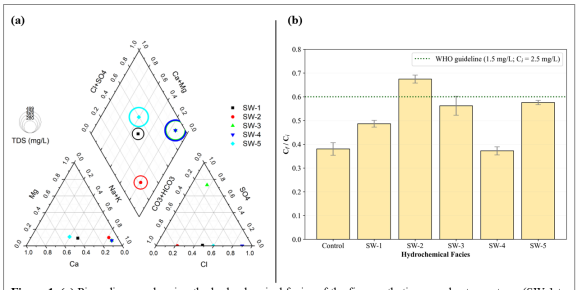

Figure 1. (a) Piper diagram showing the hydrochemical facies of the five synthetic groundwater systems (SW-1 to SW-5). **(b)** Fluoride removal performance of adsorbent under five synthetic facies expressed as C_f/C_i

References

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