

# The fate of phosphorus in groundwater systems

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Knowledge about the biogeochemical processes causing an enrichment of phosphorus in groundwater is still scarce, although elevated concentrations exceeding 1 mg L<sup>-1</sup> were found in many floodplain and delta aquifers, e.g. in South and Southeast Asia. Here, the dominating species is orthophosphate, which can contribute to the eutrophication of surface waters and is further able to mobilize toxic trace elements such as arsenic via competition for sorption sites.

We provide a broad overview of the biogeochemistry of phosphorus in groundwater systems and aim to answer the overarching question how its fate is linked to other elements. In several study areas, we applied different methodological approaches spanning from traditional chemical analyses of groundwater and aquifer material over laboratory and field experiments to isotope analysis and geochemical modeling.

We were able to attribute the release of phosphorus into groundwater to the following three major processes (see Fig. 1): (a) apatite weathering; (b) microbial mineralization of organic matter deposits, producing dissolved phosphorus as a by-product; and (c) the reductive dissolution of iron-(hydr)oxides, releasing surface-adsorbed as well as incorporated phosphorus into the groundwater [1]. Subsequently, an intensive microbial turnover of phosphorus may occur during its underground transport (d) as indicated by phosphate-bound oxygen isotope analysis. At the same time, dissolved phosphorus can be immobilized via the following pathways: (e) incorporation into secondary minerals (e.g. calcium-phosphates or iron minerals); and (f) surface adsorption [1,2]. Here, we further witnessed a preferential immobilization of phosphorus over arsenic, increasing the mobility of the latter. Which of the (im)mobilization process(es) occurs, ultimately depends on the local groundwater properties and the mineralogical composition of the aquifer material.

Overall, our results emphasize that the fate of phosphorus in aquifers is closely related to the biogeochemical cycles of calcium, carbon, iron, arsenic and possibly sulphur, which could

be utilized for *in-situ* groundwater remediation approaches.

[1] Li, Yu, Zhao, ... & Guo (2022), *Water Research* 209, 117930.

[2] Neidhardt, Winkel, Kaegi, ... & Berg (2018), Insights into arsenic retention dynamics of Pleistocene aquifer sediments by *in situ* sorption experiments. *Water Research*, 129, 123-132.

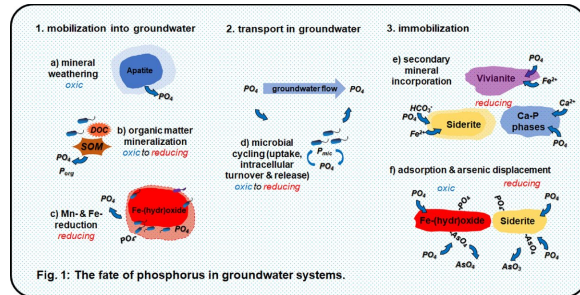


Fig. 1: The fate of phosphorus in groundwater systems.