

# Hydrological and sedimentary controls leading to arsenic contamination of groundwater in the Hanoi area, Vietnam: The impact of iron-arsenic ratios, peat, river bank deposits, and excessive groundwater abstraction

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**Abstract:** Groundwater contamination by arsenic in Vietnam poses a serious health threat to millions of people. In the larger Hanoi area, elevated arsenic levels are present in both, the Holocene and Pleistocene aquifers. Family-based tubewells predominantly tap the Holocene aquifer, while the Hanoi water works extract more than 600,000 m<sup>3</sup>/day of groundwater from the Pleistocene aquifer. Detailed groundwater and sediment investigations were conducted at three locations exhibiting distinct geochemical conditions, i.e., i) high levels of dissolved arsenic (av. 121 µg/L) at the river bank, ii) low levels of dissolved arsenic (av. 21 µg/L) at the river bank and, iii) medium levels of dissolved arsenic (60 µg/L) in an area of buried peat and excessive groundwater abstraction. Seasonal fluctuations in water chemistry were studied over a time span of 14 months. Sediment-bound arsenic (1.3-22 µg/g) is in a natural range. Arsenic correlates with iron ( $r^2 > 0.8$ ) with variation related to grain size. Sediment leaching experiments showed that arsenic can readily be mobilized at each of the three locations. Low levels of arsenic in groundwater (< 10 µg/L) generally exhibit manganese reducing conditions, whereas elevated levels are caused by reductive dissolution under iron- and sulphate reducing conditions. Average arsenic concentrations in groundwater are twofold higher at the river bank than in the peat area. The lower levels of arsenic contamination in the peat area are likely controlled by the high abundance of iron present in both the aqueous and sediment phases. With median molar Fe/As ratios of 350 in water and 8700 in the sediments of the peat area, reduced iron possibly forms new mineral phases that resorb (or sequester) previously released arsenic to the sediment. Despite similar redox conditions, resorption is much less significant at the river bank (Fe/As(aq) = 68, Fe/As(s) = 4700), and hence, arsenic concentrations in groundwater reach considerably higher levels. Drawdown of Holocene water to the Pleistocene aquifer in the peat area, caused by the pumping for the Hanoi water works, clearly promotes reducing conditions in Pleistocene groundwater. This demonstrates that excessive abstraction of water from deep wells, i.e., wells tapping water below the arsenic burdened depth, can cause a downward shift of iron-reducing conditions and concurrently mobilize arsenic along the way. Vertical migration of reduced groundwater may also impact aquifers under natural hydrological conditions. Seepage of DOC-enriched groundwater derived from degradation of organic matter in the clayey sediments at the river bank was observed to enhance (and maintain) iron-reducing conditions in the aquifer where organic matter is scarce. Once the aquifer becomes reduced, arsenic is released from the aquifer solid-hosts but additionally derives from the arsenic-enriched groundwater seeping from the clay into the aquifer. This behaviour is an

important mechanism for arsenic contamination in aquifers that might not necessarily contain enough organic matter in their sediments to induce reducing conditions independently. © 2007 Elsevier B.V. All rights reserved.

Author Keywords: Hydrology; iron-arsenic ratio; irrigation; seasonal fluctuations; sediment extraction; Water isotopes

Index Keywords: aquifer; arsenic; dissolution; dissolved organic carbon; groundwater pollution; hydrogeochemistry; iron; isotopic ratio; leaching; manganese; Pleistocene-Holocene boundary; redox conditions; resorption; river bank; Asia; Eurasia; Hanoi; Southeast Asia; Viet Nam

Year: 2008

Source title: Chemical Geology

Volume: 249

Issue: 2-Jan

Page : 91-112

Cited by: 26

Link: Scopus Link

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ISSN: 92541

DOI: 10.1016/j.chemgeo.2007.12.007

Language of Original Document: English

Abbreviated Source Title: Chemical Geology

Document Type: Article

Source: Scopus

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