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Spatial variability of arsenic and chromium in the soil water at a former wood preserving site

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Abstract

Contamination of industrial sites by wood preservatives such as chromated copper arsenate (CCA) may pose a serious threat to groundwater quality. The objective of this study was to characterise the spatial variability of As and Cr concentrations in the solid phase and in the soil water at a former wood impregnation plant and to reveal the fundamental transport processes. The soil was sampled down to a depth of 2 m. The soil water was extracted in situ from the vadose zone over a period of 10 months at depths of 1 and 1.5 m, using large horizontally installed suction tubes. Groundwater was sampled from a depth of 4.5 m. Results showed that arsenic and chromium had accumulated in the upper region of the profile and exhibited a high spatial variability (As: 21–621 mg kg^{-1}; Cr: 74–2872 mg kg^{-1}). Concentrations in the soil water were high (mean As 167 μg L^{-1}; Cr: 62 μg L^{-1}) and also showed a distinct spatial variability, covering concentration ranges up to three orders of magnitude. The variability was caused by the severe water-repellency of the surface soil, induced by the concurrent application of creosote wood preservatives, which leads to strong preferential flow as evident from a dye experiment. In contrast to soil water concentrations, only low As concentrations (<12 μg L^{-1}) were detected in the groundwater. High Cr concentrations in the groundwater (approx. 300 μg L^{-1}), however, illustrated the pronounced mobility of chromium. Our study shows that at sites with a heterogeneous flow system in the vadose zone a disparity between flux-averaged and volume-averaged concentrations may occur, and sampling of soil water might not be adequate for assessing groundwater concentrations. In these cases long-term monitoring of the groundwater appears to be the best strategy for a groundwater risk assessment.

Keywords: Unsaturated zone; Spatial variability; Arsenic; Chromium; Soil water sampling

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1. Introduction

Chromated copper arsenate (CCA) compounds have widely been used as very effective wood preservatives (Humphrey, 2002). Due to the well documented high human and environmental toxicity the European Commission issued a directive restricting the use of As-containing wood preservatives (European Commission, 2003). As of 30.06.04 no CCA-treated wood may be used for residential purposes or in marine water installations. Professional and industrial uses are only permitted under strict conditions. The U.S. EPA has also banned the use of CCA-treated wood for residential purposes as of 01.01.2004 (U.S. EPA, 2002).

There are many industrial sites contaminated by CCA which may pose a serious threat to the groundwater (Andersen et al., 1996; Lindberg et al., 1997; VADEQ, 2004). Although there have been numerous studies dealing with the effectiveness and the stability of CCA in treated wood, only a few studies have been published on the distribution and the mobility of CCA components in soils under former wood impregnation plants. A controlled laboratory study examined the addition of CCA solutions to soil columns, which led to an accumulation of contaminants in the upper soil layers. Thirty-six percent of the Cr and 13% of As applied were detected in column leachates (Allinson et al., 2000; Carey et al., 2002). Balasoiu et al. (2001) showed that chromium retention was stronger in organic than in mineral soil material, whereas arsenic was retained in both types of soil materials to a high extent (70–80%). Andersen et al. (1996) sampled soil material and soil solution at a wood impregnation site and provided evidence of both a strong accumulation and a high mobility of As and Cr. In order to characterise mobility and basic transport processes under field conditions, a need exists for in-situ monitoring of soil water concentrations at CCA-contaminated sites.

Different approaches exist for in-situ soil water sampling (Wilson, 1995). Soil water samplers applying capillary forces or a vacuum include passive capillary samplers (with a fibreglass wick) and suction cup lysimeters (Grossmann and Udluft, 1991; Boll et al., 1992; Brandi-Dohrn et al., 1996; Louie et al., 2000; Gee et al., 2002). Suction cups, although relatively easy to install and maintain, have the disadvantage that they sample a soil volume not well defined and are not suitable for the quantitative collection of macropore flow (Barbee and Brown, 1986). These samplers do not provide flux data, whereas pan type samplers can measure flux concentrations which are relevant for leaching processes (Magid and Christensen, 1993). Zero-tension lysimeters (passive pan samplers) collect free draining water, which may better reflect the chemistry of water moving through wide capillary pores and macropores (Hendershot and Courchesne, 1991; Jemison and Fox, 1992). But the collection efficiencies of zero-tension samplers are often low due to bypassing of the water flow (Zhu et al., 2002; Gee et al., 2003). Depending on the type of extraction device and therefore on the size of contact area with the soil (e.g. suction cup vs. pan sampler), the spatial range from which information is obtained by soil water sampling is very limited.

Numerous studies have dealt with the characterisation of spatial and temporal variations of soil water chemistry in forest and agricultural soils, focusing on nutrients like nitrate and sulphate and elements relevant for acidification like aluminium (Anger, 2002; Foelster et al., 2003; Alewell et al., 2004). Manderscheid and Matzner (1995) investigated the spatial heterogeneity of major ions in the soil solution of a forest soil and sampled with suction lysimeters in 59 replicates on a $25 \times 25\,\mathrm{m}^2$ plot. Coefficients of variation for element concentrations ranged from 36% to 298% indicating a high spatial variability of concentrations even in semi-natural ecosystems. The variety of applied sampling devices and investigated