Metals and arsenic in soils and corresponding vegetation at Central Elbe river floodplains (Germany)

M. Overesch [a,*], J. Rinklebe [b], G. Broll [a], H.-U. Neue [b]

[a] *Department for Geo- and Agroecology, Institute of Spatial Analysis and Planning in Areas of Intensive Agriculture, University of Vechta, P.O. Box 1553, D-49364 Vechta, Germany*
[b] *Department of Soil Science, UFZ Center for Environmental Research Leipzig-Halle, Theodor-Lieser-Straße 4, D-06120 Halle, Germany*

Soils in the Elbe river floodplains are highly polluted with metals and arsenic and a critical enrichment in the grassland herbage seems to be most likely in flood channels or within special plant species.

Abstract

Floodplain soils at the Elbe river are frequently polluted with metals and arsenic. High contents of these pollutants were detected down to subsoil layers. NH_4NO_3-extractable (phytoavailable) Cd, Ni, and Zn were elevated in horizons with high acidity. Among five common floodplain plant species, *Artemisia vulgaris* showed highest concentrations of Cd, Cu, and Hg, *Alopecurus pratensis* of As and *Phalaris arundinacea* of Ni, Pb, and Zn. Relationships were weak between metal concentrations in plants and phytoavailable stocks in soil. As and Hg uptake seems to be enhanced on long submerged soils. Enrichments of Cd and Hg are linked to a special plant community composition. Grassland herbage sampled in July/August revealed higher concentrations of As (+122%), Hg (+124%), and Pb (+3723%) than in May. To limit harmful transfers into the food chain, low-lying terraces and flood channels revealing highest contaminations or phytoavailabilities should be excluded from mowing and grazing.
© 2006 Elsevier Ltd. All rights reserved.

Keywords: Heavy metal; Arsenic; Plant uptake; Wetland soils; Elbe river

1. Introduction

During the last century large amounts of metals and arsenic from anthropogenic and geogenic sources have been accumulated in floodplains of the Elbe river system (Kowalik et al., 2003). Floodplain soils functioned as major sink for these pollutants. Soils at low-lying terraces (Mollic Fluvisols) and in flood channels (Gleysols) reveal highest concentrations of pollutants due to organic and mineral particles sedimented during frequent or extended flooding periods with low flow-rates (Devai et al., 2005; Rinklebe, 2004; Rinklebe et al., 1999, 2005). Metal and arsenic concentrations in those soils frequently exceed the threshold values of the German soil protection legislation. Commonly these polluted floodplains are used as grassland for production of hay or as pasture for cattle grazing which raises concern about possible transfers of metals and arsenic into the human food chain.

Floodplains of the Elbe river are characterized by high spatial variability of soil conditions, metal contents and mobility of metals in soil, as well as of plant community composition. Transfer of metals and arsenic into aerial plant organs shows high element and plant specific differences (Kabata-Pendias and Pendias, 2001). As a consequence, predicting actual soil–plant transfer and contamination of green fodder in floodplains is uncertain and yet insufficient for legal actions.

In the past, numerous studies have been conducted regarding mechanisms of metal uptake into agricultural and garden crops. The metal transfer into wild plants was frequently investigated on highly polluted but rather well-defined areas like mining or industrial sites (Kabata-Pendias and Pendias, 2001). Fewer studies focused on metal transfer into wild plants in more extended areas, e.g. contaminated by geogenic metal loads (Shallari et al., 1998) or by airborne deposition (Brekken and Steinnes, 2004). Research of metal fluxes in wetlands mainly focused on submerged or emergent plants (Deng et al., 2004; Qian et al., 1999). Sufficient information about metal transfer from floodplain soils into grassland vegetation is lacking.

Metal and arsenic concentrations in grassland vegetation of Elbe river floodplains are generally low and seldom correspond to stocks in soils (Krüger and Gröngröft, 2003). However, sites have been identified with plant concentrations of metals and arsenic that exceed threshold values of the German food ordinance for livestock (FutMV, 2000). Current uncertainties about seasonal, spatial and plant species related patterns of metal and arsenic contamination in floodplain vegetation have to be reduced to identify feasible management and legal actions to prevent possible transfers of metals and arsenic into the human food chain.

Our objectives were:

(a) To quantify metal and arsenic contamination in soils, selected plant species, and green fodder at highly polluted grassland sites in Elbe river floodplains.
(b) To explore relationships between concentrations of metals and arsenic in soils and plants and to evaluate the potential for seasonal differences and the associated risks of elevated pollutant uptake by livestock via grazing or feeding hay.

Fig. 1. Location of the study areas at the Elbe river in Germany.

2. Material and methods

2.1. Study areas and study sites

Both study areas and study sites have been selected after large-scale conventional soil mapping and several years of comprehensive field pedological research in the floodplains of the Elbe river (e.g. Rinklebe, 2004; Rinklebe and Langer, 2006; Rinklebe et al., 2000, 2005). The study areas are located in floodplains at the Central Elbe river in Germany. The area Wörlitz is situated at stream kilometer 242, the area Steckby at stream kilometer 284, the area Rogätz at stream kilometer 284, and the area Sandau at stream kilometer 417 (Fig. 1). The long-term annual precipitation ranges from 470 to 570 mm and the mean annual air temperature is approximately 8.0 °C (Rinklebe, 2004).

Six study sites representing common and frequently highly polluted soil units at the Elbe river were selected within these four areas. Former studies had shown a high metal contamination of soil at these sites (Rinklebe, 2004; Rinklebe et al., 1999, 2005). According to FAO/ISRIC/ISSS (1998) soils on low-lying terraces were classified as Mollic Fluvisols (FL1, FL2, FL3) and as Humic Regosol (RG1) (Table 1). Soils in flood channels were classified as Eutric Gleysols (GL1, GL2). The sites were used as extensive grassland, pasture, or fallow. All of them are periodically flooded mainly depending on snow melt (winter and spring) and heavy rainfalls (spring and summer).

2.2. Sampling, pre-treatment, and analysis of soil

At each study site, soil samples were collected in soil profiles according to genetic horizons to a depth of more than 1 m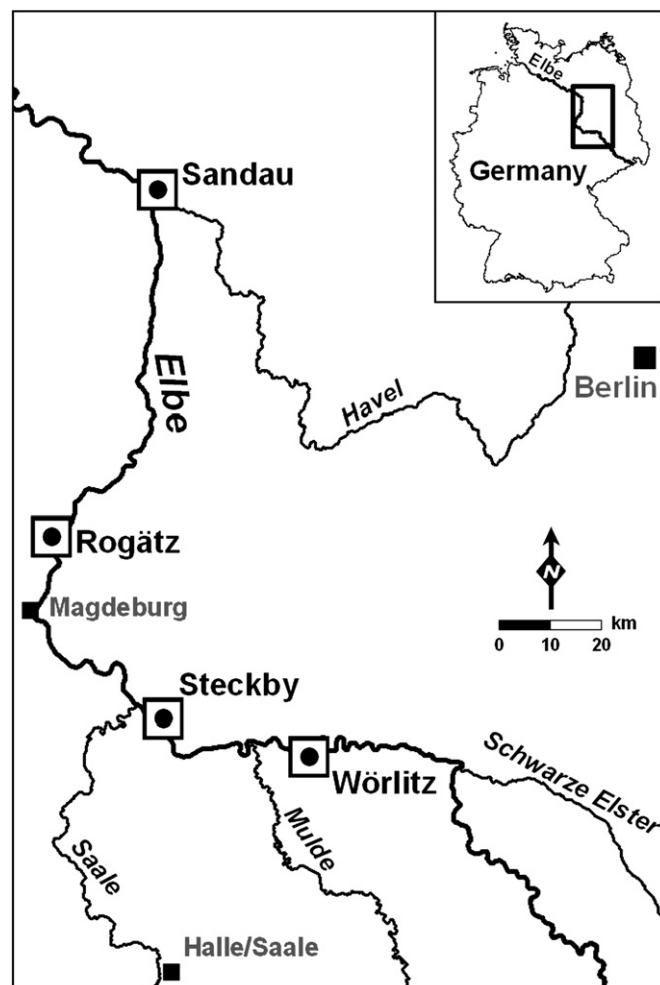 or till humus- and clay-poor sand was reached. Sampling was performed in four replicates of about 1 kg which were pooled to one sample per horizon (Rinklebe, 2004). Soil material was air dried and sieved to <2 mm. Subsamples were ground in an agate disc mill. Briefly, the soil properties were determined according to standard methods (Schlichting et al., 1995) as follows: total C (C_t) and total N (N_t) were measured with dry combustion and thermal conductivity detection using a C/N/S-Analyser (Vario EL Heraeus, Fa. Analytik Jena), inorganic C was quantified by dry combustion and IR-Detection with a C-MAT 550 (Fa. Stroehlein). Soil organic C (C_{org}) was calculated as the difference between C_t and inorganic C. Particle-size distribution was determined by wet sieving and sedimentation using the pipette sampling technique. Soil pH was measured in 0.01 M $CaCl_2$-solution mixed 2.5:1 with soil.

Total metal and As concentrations of soil samples were quantified after digestion using aqua regia (37% HCl + 65% HNO_3, 3:1) ignoring that certain parts may remain in the residuum. Phytoavailable metals were determined by extracting 2 g soil with 50 ml of 1 M NH_4NO_3 solution (Zeien and Brümmer, 1989). Horizons with sandy texture have been excluded from those analyses since preliminary studies indicated very low metal concentrations. Cr, Cu, Ni, Pb, and Zn in soil extracts were measured by inductively coupled plasma optical emission spectrometry (ICP-OES), As and Cd by graphite furnace atomic absorption spectrometry (GF-AAS) and Hg by cold vapor graphite furnace AAS (CV-GF-AAS). Blanks, triplicate measurements of metals and As in extracts, and analysis of multi-element standards (Merck) were routinely included for quality control. The given soil chemical and physical results represent arithmetic means of duplicate samples. Maximum allowable relative standard deviation between replicates was set to 10%. All concentrations