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Soil, water, and pasture enrichment of antimony and arsenic within a coastal floodplain system

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Abstract

Moderate levels of enrichment with environmental contaminants, such as arsenic (As) and antimony (Sb), have received less attention than gross contamination related to obvious point sources of pollution. Within the Macleay floodplain of north-eastern NSW it was found that approximately 90% of the floodplain is enriched in As and Sb, and 6–8% of the floodplain contains As and Sb levels greater than current Australian soil environmental investigation levels. Variation in surface and depth distributions indicated flood deposition of As and Sb across major environmental floodplain environments, with highest accumulation in modern swamp depositional environments. The soil enrichment was reflected by pasture uptake (up to 6.4 and 2.2 mg kg^{-1} for As and Sb, respectively) and elevated surface water concentrations (up to 10 and 21 times drinking guideline values and 2.9 and 6.9 times freshwater trigger values for protection of 95% of species for As and Sb, respectively) of these metalloids. Significant relationships between pasture and total soil levels imply higher relative availability than is typical at grossly contaminated sites. Implications for metalloid mobility and availability in acid sulfate soil environments in the floodplain are discussed.

Keywords: Arsenic; Antimony; Contamination; Floodplain

1. Introduction

While As has been the focus of environmental studies for decades, elevated concentrations of Sb around smelters, chemical plants, mining and mineralised areas have only recently provoked interest in the environmental behaviour and effects of this poorly studied metalloid (Filella et al., 2002). In comparison with As, there is a dearth of information on the ecotoxicology of Sb and the extent of its environmental dispersion, cycling, and chemistry in heterogeneous field systems.

Studies on Sb contamination usually concentrate on grossly contaminated areas near smelters (Ainsworth et al., 1990a,b) or old mining areas (Hammel et al., 2000). Ainsworth et al. (1990a) found elevated levels of Sb in grasses (8–336 mg kg^{-1}, related to Sb

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plant-surface deposition) sampled from a smelter site with surface soil Sb>160 mg kg^{-1}, while Hammel et al. (2000) found shoot and leaf accumulation across 19 species of up to 0.34 and 2.2 mg kg^{-1} Sb, respectively, in soils containing up to 500 mg kg^{-1} Sb.

Evaluations of inorganic land contamination increasingly rely on calculations of regional or local background concentrations as well as regional or national indicator values (ANZECC and NHMRC, 1992; Chen et al., 1999, 2001; NEPC, 1999a,b; Crommentuijn et al., 2000; Kabata-Pendias, 2000). Such calculations have the advantage of incorporating site-specific variables such as soil parent material or mineralisation into evaluations of contamination. Background Sb soil concentrations are most often cited as being <1 mg kg^{-1} (Edwards et al., 1995; Kabata-Pendias, 2000), and As <6 mg kg^{-1} (Bowen, 1979). Similar to As, evidence suggests toxicity and availability of Sb depends on its speciation (Gebel, 1997; Smichowski et al., 1998; Filella et al., 2002). Thus, moderate levels of contamination may lead to bioavailability and harmful environmental effects, if variables affecting speciation and mobility are unfavourable (e.g., redox potential, pH), and while gross contamination of As and Sb in soils has been the focus of many studies, the importance of moderate levels of Sb contamination (and to a lesser extent As) may have been overlooked.

The current Australian Ecological Investigation Limit (EIL) is set at 20 mg kg^{-1} for both As and Sb in urban areas. These are taken as interim default values as regional (non-urban) limits have not been determined. Site-specific investigations are recommended where these limits are exceeded (ANZECC and NHMRC, 1992; NEPC, 1999a). Moderate enrichment of As and Sb (up to 2 times the current Australian soil investigation limits) is an emerging issue across the Macleay Catchment coastal floodplain of north-eastern NSW, Australia. It has been shown that historic mining practices and release mechanisms from mineralised areas in the upper catchment have produced a traceable sediment dispersion train of As and Sb over 300 km long, ranging from several hundred mg kg^{-1} in actively mined and mineralised regions of the upper catchment, to values persistently greater than catchment background values (7.9 and 1.1 mg kg^{-1} for As and Sb in stream sediments, respectively) within the coastal floodplain (Ashley and Graham, 2001; Ashley et al., 2003). Water values in the upper catchment are enriched, with As and Sb concentrations up to 1–3 orders of magnitude greater than current drinking water guidelines (Ashley and Graham, 2001). This contamination is chiefly sourced from historic (pre-1970) mining waste disposal practices involving the stibnite and arsenopyrite-bearing ore and mineralised host rock in the Hillgrove area (Ashley et al., 2003). This is the largest known anthropogenic dispersion of Sb in Australia. Limited previous floodplain sampling identified elevated As and Sb levels in sediments of up to 26 mg kg^{-1} of As and 18 mg kg^{-1} Sb. The main objective of this study was to determine the spatial and vertical distribution of As and Sb contamination across the Macleay coastal floodplain, and to investigate possible uptake of these contaminants into selected pasture species.

2. Materials and methods

2.1. Site description

The Macleay catchment coastal floodplain is located in north-eastern New South Wales, Australia, where it forms the major terrestrial depositional and estuarine environments of the Macleay catchment and the second largest river on the New South Wales north coast, the Macleay River. The floodplain comprises around 5% of the catchment's 11 500 km^2 (Department of Public Works, 1989; Fig. 1).

The town of Kempsey is the major urban area (pop. 10235 (ABS, 2003)), (lat=31°05′00″S, long=152°50′00″E) with several smaller towns along the Macleay River and coast. The climate is temperate to sub-tropical, with a maximum monthly temperature of 29.2 °C in January, and a minimum of 5.7 °C in July (CBM, 2003). The average annual rainfall at Kempsey is 1220 mm, with the highest falls occurring December to April (Atkinson, 1999; CBM, 2003). The area experiences frequent flooding, with a 1 in 100-year flood covering an estimated 56 000 ha in the Kempsey Shire boundary (Laurie et al., 1980), almost 100% of the defined floodplain area. Smaller floods of 5- and 10-year recurrence interval cover almost the same area, but to a shallower depth (Laurie et al., 1980; Department of Public Works, 1989).

The coastal floodplain system is dominated by modern swamp (relict estuarine) and alluvial flood-