DEPOSITION AND STORAGE OF SOLID-BOUND HEAVY METALS IN THE FLOODPLAINS OF THE RIVER GEUL (THE NETHERLANDS)

H. LEENAERS*

Department of Geography, University of Utrecht, P.O. Box 80.115, 3508 TC Utrecht, The Netherlands

(Received December 1989)

Abstract. Because of past mining activities, the floodplains of the River Geul are polluted with heavy metals. The continuous supply of fresh sediments during floods has caused the floodplain soils to exhibit large quality variations in time. By measurements of $^{137}$Cs deposition rates in part of the floodplain area were determined at 0.4 to 2.7 cm yr$^{-1}$. Analysis of soil metal concentrations at various depths at 65 locations, revealed that the upper 40 cm of the soil profile deposited during the past 30-45 yr, exhibit the highest metal levels. The geostatistical interpolation technique kriging was used to map actual and past pollution patterns. It was shown that, as a result of variable deposition rates, the spatial correlation structure of soil metal concentrations becomes less clear with increasing depth/age. Kriged maps of average metal concentrations in the upper 100 cm of the soil profile provided the basis for the calculation of the mass storage of heavy metals.

Introduction

Historic metal mining has caused the widespread dispersal of heavy metals in many fluvial systems. Studies conducted in a number of catchments in the UK (e.g. Lewin and Macklin, 1987), the U.S.A. (Marron, 1986; Moore et al., 1989) and the Netherlands (Leenaers et al., 1988; Rang et al., 1986) have shown that long after their abandonment, the mines may still provide a source of metals to the fluvial system. Old spoil heaps and contaminated streambank deposits may continue to supply contaminants to the river channel as a result of leaching and erosion processes. Floodplains may act as sinks of sediment-bound contaminants during periods of inundation, providing long term storage (Bradley, 1987; Marron, 1986; Lewin and Macklin, 1987).

Relatively little information exists regarding the magnitude of depositional losses that may occur (Walling et al., 1986). A number of authors have shown that fallout $^{137}$Cs may be a useful tracer for the determination of erosion or deposition rates in a variety of environments, such as reservoirs (Ritchie et al., 1973; Robbins et al., 1977), agricultural fields and watersheds (McHenry and Ritchie, 1977a, b; Bachhuber et al., 1987; Ritchie et al., 1974; McCallan et al., 1980; Loughran et al., 1982; Martz and De Jong, 1987; Vandenberge and Gulinck, 1987; Walling et al., 1986) and river floodplains (Ritchie et al., 1975; Walling et al., 1986; Walling and Bradley, 1988).

Because of the continuous supply of fresh sediments within a floodplain, the quality of the alluvial topsoils in a contaminated river system may exhibit large variations in time. Given the fact that the contaminants may restrict the landuse in these areas, quantitative mapping techniques are required that delineate up-to-date pollution zones. Regionalized variable theory (Matheron, 1971) provides a convenient means of summarizing soil spatial

* Present Address: CSO, Consultants for Environmental Management and Survey, P.O. Box 30, 3734 ZG Den Dolder, The Netherlands.

variability in the form of a semi-variogram that can be used to estimate weights for interpolating – by kriging – the value of a given soil property at an unsampled location. This technique has been used recently for estimating spatial patterns of contaminants (Gilbert and Simpson; 1985, Starks et al., 1987; Leenaers et al., 1989). When studying floodplain soil pollution, these techniques can also be used to reconstruct past pollution patterns once the local deposition rates are known, and the bulk storage of contaminants may be estimated.

Because of past mining activities, the floodplain soils of the River Geul (The Netherlands) are polluted with heavy metals, particularly zinc, lead and cadmium (Leenaers et al., 1988; Leenaers and Okx, 1989; Rang et al., 1986). Because of the high concentrations of heavy metals in recent flood deposits (Leenaers et al., 1988) and the often observed large amounts of sediments that are deposited during individual floods, investigations were carried out to provide insight in the rate of sediment deposition and the implications for the quality of topsoils in the floodplains. $^{137}$Cs was used to estimate deposition rates at a number of locations and contour maps of soil metal concentrations at various depths below surface were constructed from 65 data by kriging for a 2 km long part of the Geul floodplain. In addition, these data were used to estimate the bulk storage of heavy metals in floodplain soils.

The Study Area

The River Geul is a tributary of the River Meuse (Figure 1). From its source to its confluence with the Meuse it is 56 km long, of which 20 km are in Belgium, and it drops 242 m. The catchment covers 350 km$^2$. In the southern part of the Netherlands, the Geul valley is incised into a loess-covered plateau which is underlain by Cretaceous limestone. The floodplain soils in the Geul valley have a relatively coarse texture and contain only 10-20% clay (Van den Broek and Van der Marel, 1964).

The exploitation of the zinc and lead ores in Plombières and Kelmis (Figure 1) began in the thirteenth century and continued until 1938, when the last mine closed. The heyday of mining was in 1850-1880. The mining and processing techniques were inefficient and resulted in high concentrations of ore particles and metal-rich spoil in the effluent, which was discharged directly into the river. The reject material and tailings were dumped in large heaps, some of which still exist. An additional input of heavy metals is provided by the erosion of older, locally highly contaminated streambank deposits during high flow stages.

The River Geul discharge largely depends on amounts of rainfall. At the Dutch-Belgium border its average flow is 1 m$^3$s$^{-1}$ and the maximum discharge is of the order of 30 m$^3$s$^{-1}$. These values increase to respectively 2 and 60 m$^3$s$^{-1}$ as the Geul flows towards its confluence with the Meuse. The Gulp, the only major tributary of the Geul, discharges some 100 l s$^{-1}$ at low flow and 7 m$^3$s$^{-1}$ at peak flow into the Geul. During low flow, the suspended load of the Geul river is very low and of the order of 10-50 mg l$^{-1}$. At high flow stages the suspended load may increase to 4000 mg l$^{-1}$, causing high rates of sedimentation on the floodplains.