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Trends in soil erosion and sediment yield in the alpine basin of the Austrian Danube

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Abstract For the first time this study quantifies the increases in soil erosion and sediment yield within the overall alpine basin of the Austrian Danube, as well as the basins of three typical major tributary rivers. The research is based on topographic data, as well as land use information for the period from 1950 to 1990, which were published by the Austrian Statistical Central Office. Due to the large-scale approach, the Universal Soil Loss Equation was used to calculate average soil erosion rates for typical erosion-controlling parameter combinations found in the basin. By applying an adapted sediment delivery ratio, the sediment yields for the sub-catchments of the major basins were estimated. Recently monitored suspended sediment concentration data for the rivers indicated an increasing trend for sediment yield. The results confirmed this trend, which can be partly explained by changes in land use as well as agricultural management practices, especially the expansion of areas of maize cultivation, often onto the steep hillslopes of the sub-alpine regions.

INTRODUCTION

The Austrian part of the drainage basin of the Danube, with its strong alpine characteristics, has an area of approximately 75 000 km^2. As a geologically young mountain system the Alps still represent an active source of various types of natural sediment, e.g. landslides of all different sizes during storm events. However, intensification of human activities (e.g. the development of alpine tourism and of new settlements requiring flood protection schemes and often causing deforestation, and the expansion of agriculture in (sub)alpine regions etc.) are disturbing the fragile status of the natural sedimentological balance of the Alps.

Trend analyses show that agriculture represents the major negative cause of soil erosion in the (sub)alpine region (Summer & Klaghofer, 1989; Klaghofer & Summer, 1990; Klaghofer & Hintersteiner, 1993; Klaghofer *et al.*, 1994). The expansion of farmland into hilly/mountainous areas with steep slopes, and changes in land use as well as in land management techniques, often forced on the farmers by economic pressure, have significantly increased soil erosion rates as well as sediment yields from the different sub-catchments within the Danube drainage basin during the last 40 years. These impacts on the sedimentological behaviour of the Austrian Danube have been recently observed and reported (Radler *et al.*, 1993; Summer *et al.*, 1994a,b; Summer & Zhang, 1994).

This is the first study that quantitatively estimates the change in rates of agricultural soil erosion as well as in sediment yields within the overall Austrian drainage basin of the Danube and three important tributaries (Fig. 1). Based on the Universal Soil Erosion Equation (USLE), average soil erosion rates have been estimated (Wischmeier & Smith, 1978). By the application of specially adapted Sediment Delivery Ratios (*SDR*) for alpine areas (Vanoni, 1975; Klaghofer *et al.*, 1992) the sediment yields of the major sub-catchments of the Inn, Enns and Traun rivers have been calculated. In carrying out this study, use was made of land use information for the years 1950 to 1990 (Austrian Statistical Central Office, 1950; 1960; 1970; 1979; 1990) and topographic information on slope characteristics derived from the digital elevation model (DEM) of Austria. Its grid size ranges between 30 × 30 m and 50 × 50 m.

THE RIVER INN BASIN

The total basin area of the River Inn in Austria is about 17 000 km^2. Forty three percent of this is used for agriculture, 35% for forestry and 22% is unproductive. The size of the overall agricultural area has hardly changed between 1950 and 1990, but the proportion of cultivated land has decreased while the area of grassland has increased. Analysis of crop data shows that the area planted to maize has increased from 2% of the cultivated area in 1950 to 25% in 1990. Changes in the other erosion-relevant crops such as beet, potatoes and spring corn will have had hardly any impact on the sediment loads. Assuming a rainfall erosion index *R* of 100 kJ mm m^{-2} h^{-1} and a soil erodibility index *K* of 0.5, estimates of erosion rates were obtained using the USLE. Under the common Austrian land management practice, it can be further assumed that 75% of the corn and maize as well as 25% of the potatoes and beet are planted on sloping land. The average

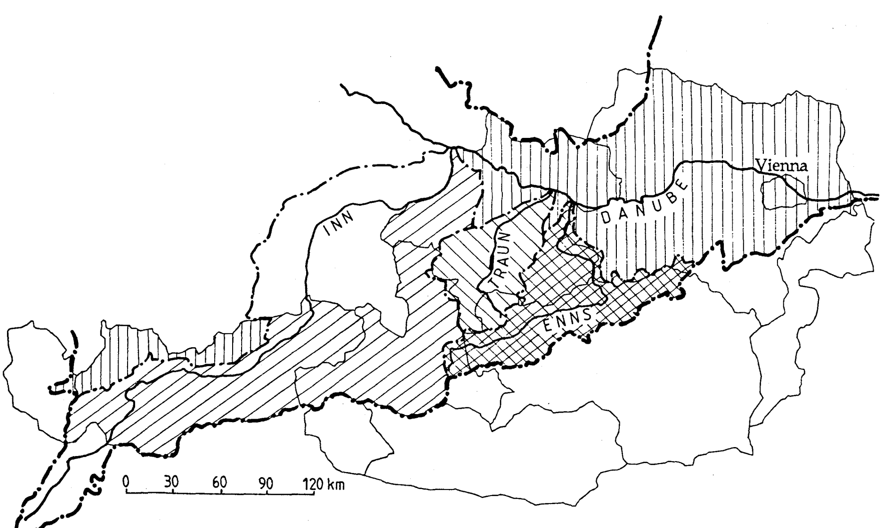

Fig. 1 Map of the Austrian Danube basin showing the location of the rivers Inn, Enns and Traun.

slope gradient (*S*) is estimated to be 10% and the typical slope length (*L*) is 50 m. This provides a slope factor (*LS*) of 1.76. The crop practice factor (*C*) for maize is 0.33, for potatoes 0.24, for beet 0.21 and for spring corn 0.06.

In the year 1950 *c.* 460 000 t of soil were eroded. The average sub-catchment size for each major tributary of the River Inn is *c.* 13 km^2. This gives a sediment delivery coefficient (*SDR*) of 0.2. Hence, a sediment yield of 92 000 t year^{-1} can be calculated. Taking account of the changed crop proportions within the River Inn basin, a sediment yield of 128 000 t was estimated for 1990 under the same basic conditions.

THE RIVER ENNS BASIN

The River Enns basin covers approximately 9000 km^2 In the year 1950, 37% was used for agriculture, 46% for forestry and 17% consisted of unproductive land. The agricultural land decreased up to 1990 by *c.* 5% while area the used for forestry increased by the same amount. In the year 1950 there was no maize planted. By 1990 the area planted to maize had increased to 23% of the agricultural area. The area of potatoes, beet and spring corn reduced slightly up to 1990. The calculation of the soil erosion was undertaken using similar climatic, topographic and morphological assumptions as for the River Inn basin. The total erosion estimated by the USLE was 227 000 t for 1950. With an *SDR* coefficient of 0.2 for appropriate sub-catchments of *c.* 15 km^2, a sediment inflow to the River Enns of 45 400 t year^{-1} has been calculated. In 1990, under changed land use management, 407 000 t of soil were eroded, giving a sediment yield of 81 400 t.

THE RIVER TRAUN BASIN

The basin of the River Traun drains an area of *c.* 5000 km^2. In 1950, 43% of this area was used for agriculture, 40% consisted of forests and the unproductive area covered 17%. While the area of agricultural land did not change significantly up to 1990, the area of intensive farming increased dramatically and the area under grassland was consequently reduced. Analysis of crop data for this 40 year period clearly shows the expansion of maize areas from non-existence in 1950 to 25% in 1990. The areas of potatoes, beet and spring corn therefore decreased. Using comparable catchment conditions for the River Traun as for the other basins, the soil loss computation produced a value of *c.* 326 000 t for the year 1950. Assuming an *SDR* coefficient of 0.2 (the size of the relevant sub-catchments ranges between 10 and 15 km^2) an input into the river of *c.* 65 000 t year^{-1} is obtained. Under the different land use and/or crop pattern for 1990, a similar calculation gives a soil loss rate of 642 000 t and a delivery of 128 000 t of sediment to the river.

THE REMAINING BASINS OF THE AUSTRIAN DANUBE

The remaining area of the overall Austrian basin of the Danube (excluding the Enns, Traun and Inn basins) is about 44 000 km^2 In 1950 agriculture occupied 52% of this area and 34% was under forestry. The unproductive area accounted for 14%. By 1990 the agricultural area had decreased to 49% whereas the forest area increased to 39%. The area used for maize production increased between 1950 and 1990 by 12%, from 4% to 16%. An increase of winter corn was observed, while the area under potatoes and beet decreased.

In the remaining Danube regions, an average R index of 70 was assumed. These areas comprise several catchments characterized by flat areas, basins and plateaux, with level topography or only slight gradients. Overlaying a crop map onto a topographic map showed that for these regions only 50% of corn and maize production and only 25% of potato and beet production was located on hillslopes. An average slope length (L) of 75 m was estimated as a reasonable approximation, and a mean slope gradient (S) of 10% was derived for the hilly portions of the area. Hence an LS factor of 2.15 was obtained and a value of 0.5 was assumed for the K factor. Under the assumption of the land use proportions and cropping patterns described previously and using average climatic and geomorphological conditions, an annual rate of soil loss of 1 969 000 t was estimated for 1950. Applying an *SDR* coefficient of 0.2 gives a sediment yield of *c.* 394 000 t for the year 1950. Taking account of the land use changes up to 1990, the soil erosion rate is estimated at 2 209 000 t year^{-1} and the sediment yield at *c.* 442 000 t year^{-1} for 1990.

SEDIMENT IMPACT OF THE GERMAN BASIN ON THE AUSTRIAN DANUBE

The sediment dynamics of the Austrian Danube are influenced not only by the northern alpine regions of the Austrian Danube basin, but also by the intensively used agricultural areas of the catchments in southern Germany with partly sub-alpine characteristics. The area of potential soil erosion extends to about 21 000 km^2. Using the estimated annual soil erosion rate of 17.1×10^6 t year^{-1} (Auerswald & Schmidt, 1986), a sediment input to the German Danube of around 3.4×10^6 t year^{-1} can be estimated, assuming an *SDR* coefficient of 0.2. It is thus evident that the German sediment input is much higher than the input from the Austrian basin. This can be explained by the following factors:

(a) Larger areas of intensively used agricultural land exist in the German area, in comparison to the Austrian basins; and
(b) soil erosion rates are higher in Germany (8.1 t ha^{-1} year^{-1}) than in Austria (3.0 t ha^{-1} year^{-1}) due to contrasts in the intensity of different land use practices between these two countries.

However, this German data set, the only one available, represents a status-quo situation from the 1980s and takes no account of temporal trends.

CONCLUSIONS AND DISCUSSION

From 1950 to 1990 the changes within each of the major sub-basins of the Austrian Danube basin showed a highly variable increase in sediment production (erosion rate as well as sediment yield). In the River Inn basin an increase of 40% was estimated, whereas the increase was 80% in the River Enns basin and the values almost doubled in the River Traun basin. The remaining parts of the Austrian basin of the Danube showed an increase of *c.* 12%. Hence, for the entire Austrian basin (including the three listed basins plus the remaining part of the total basin) an average increase of 32% was derived for the 40 year period.

The impacts in the eastern parts of the Danube basin were more dramatic than in the alpine areas of western Austria. Three plausible reasons can be given as an explanation for these trends in erosion and sediment yield.

(a) More intensive agricultural activities in the lower alpine areas of eastern Austria in comparison to western Austria with its alpine characteristics. Intensive agriculture has expanded in the sub-alpine areas of eastern Austria. Forestry and grassland with stock farming is the tradition and hence the dominant form of land use in western Austria. Spatial limitations on the availability of suitable farmland for intensive

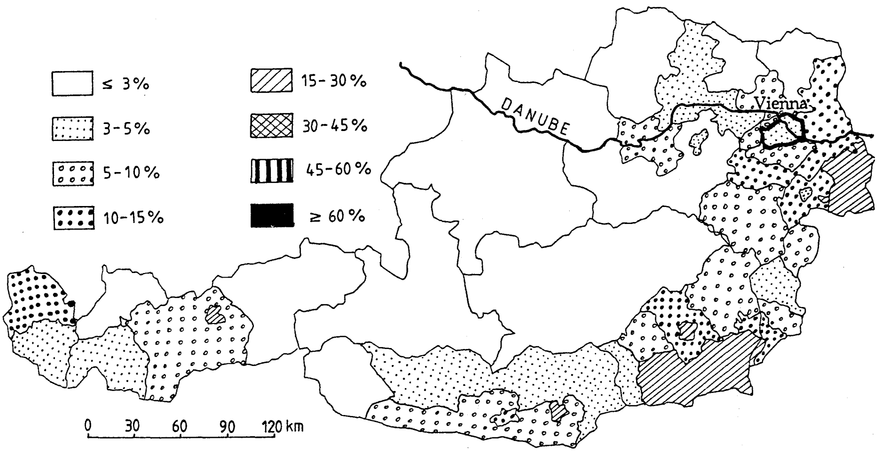

Fig. 2 Maize farming in Austria in 1960, showing the maize area as a percentage of the arable land (based on Klaghofer & Hintersteiner, 1993).

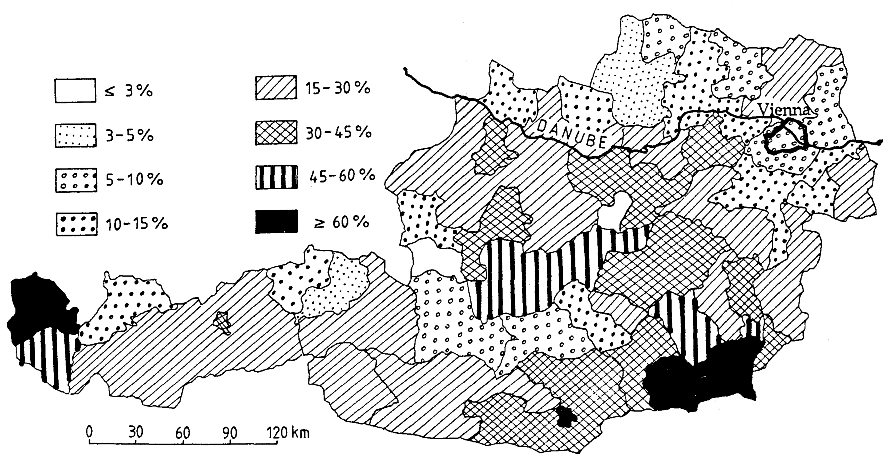

Fig. 3 Maize farming in Austria in 1986, showing the maize area as a percentage of the arable land (based on Klaghofer & Hintersteiner, 1993).

agriculture, due to extreme topographic, climatic, etc. conditions, limit the increase in soil erosion and sediment yield in western Austria.

(b) The increase of the economically important area of maize production in the Danube basin from 4% in 1950 to 16% in 1990 (Figs 2 and 3).

(c) The new maize production areas in the sub-alpine regions were often established on high slope gradients without considering contour farming or other appropriate soil conservation strategies. The young maize plants do not cover the soil properly during the spring rainfall season in the Alps, which is characterized by high precipitation intensities caused by severe local storm systems.

Although changes in land use, management practices and areal expansion cannot alone explain all of the recent changes in the sediment dynamics of the Danube, they are clearly important.

It must also be emphasized that the procedures used for calculating soil loss rates and sediment yield provide only approximate estimates. However, the estimates obtained coincide with the evidence provided by the monitored long-term sediment dynamics in the listed rivers. Nevertheless, the results of this study cannot explain the sediment dynamics of single storm events and associated floods.

However, for the first time, the results presented not only focus on the dramatic development that has occurred in parts of the Alps on a large-scale as well as from an on-site point of view, but they also indicate the location and the source of the problem. In addition, Klaghofer & Hintersteiner (1993) provided the first available data analysis indicating the goal for future research activities in soil erosion control in the Alps. For these purposes only physically-based approaches that have the capability to consider the surface transport in combination with the geomorphological complexity of the alpine landscapes can give a proper picture of the non-point source erosion dynamics (Tayfur & Kavvas, 1994). Only such a tool will then allow the predictive development of efficient soil conservation strategies, taking into account the urgent need for integrated basin management in this region.

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