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Major components of a sediment budget for four river catchments in Poland

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Abstract Two major components of catchment sediment budgets, upland erosion and sediment yield, have been estimated and compared for four river systems located in the southern mountainous part of Poland. The river catchments have areas ranging from 297 to 957 km^2, and are characterized as having relatively high intensity denudation processes in Poland. Upland erosion has been estimated with the use of the universal soil loss equation (USLE), for which erosive factors had been computed for local climatic conditions (using a 29-year rainfall record). Sediment yields have been estimated on the basis of long-term measurements. Specific sediment yields in the catchments vary from 35 to 110 t km^{-2} year^{-1}, whereas sediment delivery ratios vary from 3 to 34%.

Key words delivery ratio; sediment budget; sediment yield; USLE

INTRODUCTION

Sediment yields (expressed in t year^{-1}) have been estimated for about 50 gauging stations in Poland, based on 40-year records of suspended sediment transport (Brański & Banasik, 1996). Two major components of catchment sediment budgets, upland erosion and sediment yield, have been computed, and sediment delivery ratios have been estimated for four of the smaller of the above-mentioned catchments. The river catchments (Vistula upstream of Skoczow, Sola upstream of Zywiec, Skawa upstream of Wadowice, and Biala Tarnawska upstream of Koszyce Wlk., Fig. 1) are located in the southern mountainous part of Poland, and have watershed areas ranging from 297 to 957 km^2. Cropland occupies from 22% to 53% of the catchments. Land-use data and other basic characteristics of the four catchments are presented in Table 1.

Table 1 Basic characteristics of the investigated river catchments.

River	Gauging station	Drainage area (km^2)	Elevation (m a.s.l.)		Land use (%)		
			Maximum	Minimum	Cropland	Grassland	Forest
Vistula	Skoczow	297	1112	289	22	17	61
Sola	Zywiec	785	1323	347	30	10	60
Skawa	Wadowice	836	1725	259	54	11	35
Biala Tarn.	Koszyce Wlk.	957	940	194	54	16	30

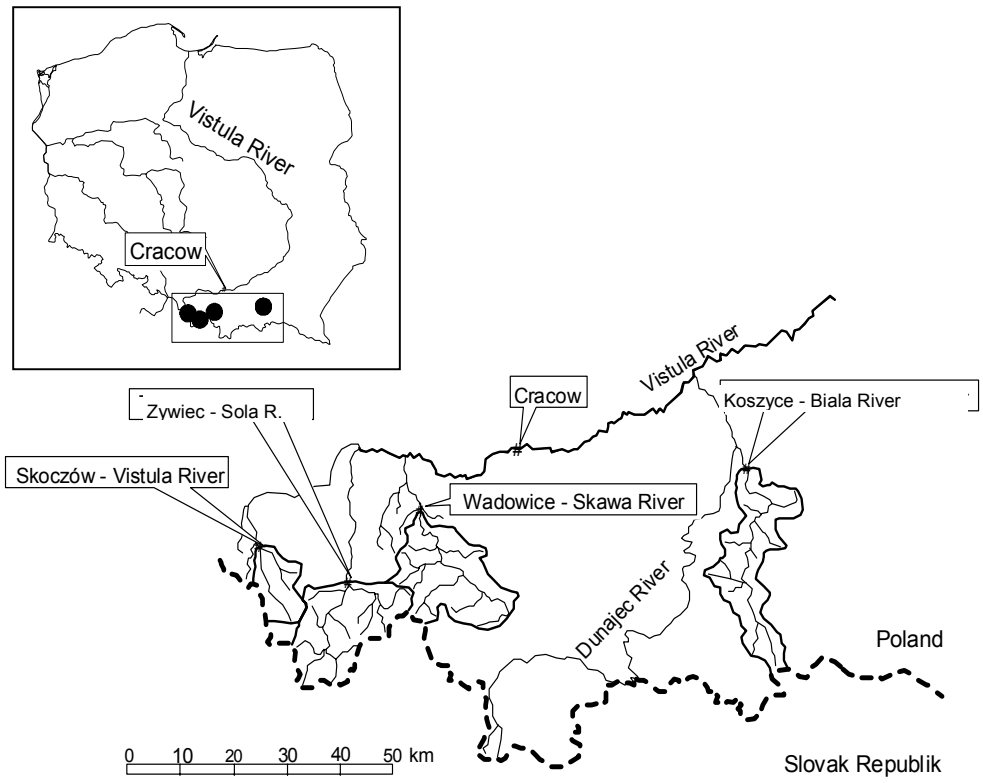

Fig. 1 Location of the four river catchments.

Upland erosion has been estimated with the use of the universal soil loss equation (USLE), for which erosive factors have been computed for local climatic conditions (using a 29-year rainfall record). The catchments are characterized in Poland as having relatively high intensity denudation processes (denudation indices expressed in t km^{-2} $year^{-1}$ range from 35 to 110).

THE METHOD OF ESTIMATING SEDIMENT YIELD

Systematic data collection on fluvial suspended sediment concentrations has been carried out by the State Meteorological and Hydrological Service (IMiGW, Institute of Meteorology and Water Management) in a hydrological network covering the whole country, beginning in the 1950s (Brański, 1981, 1994; Brański & Banasik, 1996). Suspended sediment samples are collected manually from a pre-selected point in river cross sections. Two 1 l samples are collected, usually using the standard PIHM-1 sampler (Paslawski, 1973). Time intervals between samples varied from a few hours to five days, depending on the discharge, and the type of river (Paslawski, 1973). Based on the simultaneous measurement of suspended sediment concentration in the entire cross-section (C_m), and the concentration at the selected point in the cross-section (C_p), a relationship $C_m = f(C_p)$ was established for each gauging station. These relationships, together with a time series of C_p concentrations and their associated discharges Q, were used to estimate the annual values of suspended sediment yield from the formula:

Table 2 Mean annual discharge and sediment yield for the four river catchments.

River	Gauging station	Discharge (m^3 s^{-1})	Sediment yield (10^3 t $year^{-1}$)	Specific sediment yield (t km^{-2} $year^{-1}$)	Period of measurement
Vistula	Skoczow	6.2	10	35	1956–1990
Sola	Zywiec	15.0	87	111	1951–1990
Skawa	Wadowice	12.6	68	82	1956–1990
Biala Tarn.	Koszyce Wlk.	8.7	92	96	1956–1990

$$R = 0.0864 \sum_{i=1}^{d} C_{mj} \cdot Q_j \quad (1)$$

where R is the annual sediment yield (t $year^{-1}$), C_{mj} is the mean daily suspended sediment concentration (g m^{-3}), Q_j is the mean daily discharge (m^3 s^{-1}), and d is the number of days in the year. Mean annual values of discharge, sediment yield and specific sediment yield for the four studied catchments are given in Table 2.

THE METHOD OF ESTIMATING UPLAND EROSION

The classical "Universal Soil Loss Equation" (USLE), developed by Wischmeier & Smith (1978), has been applied to estimate upland erosion in the four river catchments. Rainfall and runoff erosivity have been estimated from the local rain gauge at Limanowa; the erosive factor had been estimated during previous investigations, based on a 29-year pluviographic rainfall record, as 114 MJ cm ha^{-1} h^{-1} (Banasik & Górski, 1993; Banasik *et al.*, 1995, 2001). The two main soil types are skeletal soil and loamy soil, with the USLE soil erodibility factor (K) estimated as 0.109 and 0.374 t h MJ^{-1} cm^{-1}, respectively. Average watershed slope, estimated by the contour-length method (Williams & Berndt, 1976) ranges from 5.9% in the Biala Tarnawska catchment to 23% in the Vistula catchment. The drainage density method was used to estimate average catchment slope length. There is significant forest cover in each of the catchments, ranging from 30% to 61%. Cultivated crops include corn, grains (oats and rye), clover, and potatoes. The average values for the USLE parameters, as well as the estimated soil losses for the analysed catchments are shown in Table 3.

Table 3 Average values for the USLE factors and soil losses.

River	Gauging station	Soil erodibility factor K (t h MJ^{-1} cm^{-1})	Topographic factor LS (-)	Land-use and control practice factor CP (-)	Soil losses (t km^{-2} $year^{-1}$)
Vistula	Skoczow	0.182	16.0	0.033	1100
Sola	Zywiec	0.184	19.4	0.043	1100
Skawa	Wadowice	0.172	8.23	0.075	1200
Biala Tarn.	Koszyce Wlk.	0.155	2.16	0.076	290

Table 4 Comparison of *DR* (delivery ratio) estimated in the investigation with the *DR* according to Roehl (1962).

River	Gauging station	Sediment yield) (10^3 t year^{-1})	Upland erosion (10^3 t year^{-1})	*DR* from investigation (%)	*DR* acc. to Roehl (%)
Vistula	Skoczow	10	330	3	9.4
Sola	Zywiec	87	830	10	6.5
Skawa	Wadowice	68	1000	7	6.3
Biala Tarn.	Koszyce Wlk.	92	270	34	6.0

SEDIMENT BUDGET AND CONCLUSIONS

Values for the main components of the sediment budgets, sediment yield, and upland erosion, as well as for the delivery ratios for the four investigated catchments are provided in Table 4. The sediment yield range from 10×10^3 to 92×10^3 t year^{-1}, and upland erosion from 270×10^3 to 1000×10^3 t year^{-1}. Average values for soil losses within the four catchments range from 290 to 1100 t km^{-2} year^{-1} (Table 3). Specific sediment yield in the catchments ranges from 35 to 110 t km^{-2} year^{-1} (Table 2), and are among the highest values found in Poland, mainly because of topographic (steep slopes) and climatic conditions (high annual erosivity, particularly in June when only limited plant cover exists).

Sediment delivery ratios were computed from the formula:

$$DR = 100\% \, SY/UE \tag{2}$$

where *DR* is the delivery ratio in percent, *SY* is the catchment suspended sediment yield in t year^{-1}, and *UE* is the upland erosion in t year^{-1}. The computed delivery ratios range from 3 to 34%, and have been estimated for each of the four catchments. They are listed in Table 4, with *DR* estimates based on the relationships with the catchment areas (Roehl, 1962). For two of the four investigated catchments (Sola and Skawa rivers), the *DR* values estimated in this investigation are very close to those developed in 1962 by Roehl (10 and 7% can be assumed to be in reasonable agreement with 6.5 and 6.3%, respectively). For the two other catchments, the differences are greater. For the Vistula River, the estimated *DR* is 3%, whereas, according to Roehl (1962), it is 9.4%, and for the Biala Tarnawska River the values are 34 and 6.0%, respectively. The data indicate that, beside catchment area, other factors, such as catchment shape, relief/length ratio and bifurcation ratio (Williams, 1977; Walling, 1983) should be determined to provide better estimates of the delivery ratios.

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