Assessment of suspended load trapped in a small reservoir related to the erosion in a loess basin

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Abstract Carpathian river basins are subject to strong erosive processes. The intensity of these processes is especially evident in the loess river basins. Loess covers the Cretaceous formation over almost the total area of the basin of the River Dlubnia (left-hand affluent of the River Vistula) with a layer about 15 m thick. A relationship has been developed between water discharge and suspended load in separate hydrological periods. After determining the physiographical features of the river basin, the intensity of the erosive processes was assessed using the modified soil loss equation (MUSLE) developed from the USLE of Wischmeier & Smith (1965). As a result the suspended load trapping ability in a small reservoir related to the erosive processes has been determined.

INTRODUCTION

The proper determination of the intensity of erosive processes, such as those that occur in loess basins, presents great difficulties. The application of intermediate methods leads to considerable errors. The intensity of these processes can be assessed by means of water turbidity measurements. Based upon a period of 23 years of measurements of water turbidity and the rate of flow being determined each day the amount of suspended load transported to a small reservoir of 228×10^3 m^3 capacity, in the basin of the River Dlubnia, could be determined. The usefulness of the soil loss equation MUSLE was evaluated and allowed for the determination of the intensity of erosive processes in a loess basin.

THE INVESTIGATED BASIN

Observations were undertaken in the basin of the River Dlubnia (a left-hand tributary of the River Vistula). The area of the basin under investigation was 218 km^2. This territory is incised by a dense network of valleys going deep into the loess layer and in some places their bottom reaches and cuts into the marl subsoil (Dynowska & Tlałka, 1970). The percentage distribution of gradients in the basin is given in Table 1 and their areal distribution is shown in Fig. 1.

The basin of the River Dlubnia is on Jurassic, Cretaceous, Tertiary and Quaternary formations. Jurassic formations occur in the northwest part of the basin. Cretaceous formations occur in the central part of the basin in the form of marls and limestones. In consequence of cracks both limestone as well as marls are aquiferous and constitute a rich reservoir of underground water.

Table 1 Slopes intervals—River Dlubnia.

Slope interval (%)	Area: (km^2)	(%)
0–3	51.41	23.70
3–6	60.56	27.78
6–10	64.30	31.24
10–20	28.69	11.27
20–30	10.86	4.96
>30	2.28	1.05
Total	218.10	100.00

Almost the whole area of the basin of the River Dlubnia is covered with a layer of loess and the depth on Cretaceous formations can be 15 m. This layer is deeper in the valleys than on the ridge. This shows that the loess has been partly or completely washed or blown off the ridges. In general loess is permeable and is characterized by a high water capacity.

Apart from the loess soil a part of the area is covered with fertile soils formed on Jurassic Limestone and Cretaceous marls (Bednarczyk *et al.*, 1988). Information on agricultural use of the examined basin is given in Table 2.

The majority of this area is cultivated. Most of the fields under cultivation are ploughed along the slope which accelerates the water runoff, hence increasing soil erosion. During heavy rainfall the ploughed furrows form a sort of small chute by which the rainwater flows readily downwards carrying small particles of soil.

Particularly intensive runoff takes place when there is no plant cover in the fields (autumn and spring) (Bednarczyk *et al.*, 1988).

ASSESSMENT OF THE TRANSPORTED SUSPENDED LOAD

Every day measurements of the rate of flow and examination of its turbidity were undertaken to monitor the suspended load transported by the River Dlubnia. Turbidity was determined 3 times a day which is in agreement with the frequency of measurements of the rate of flow. It was significant to determine the relationship:

$$N = f(Q) \quad (1)$$

where:
N = water turbidity ($g\ m^{-3}$), and
Q = discharge of water ($m^3\ s^{-1}$),

In the existing elaboration the above-mentioned relationship was determined on the basis of the data from a whole hydrological year; this does not take into account the origin of the load entering the river. The course of this process differs for particular periods of the year and this is of great importance in the case of loess basins. Since a loess soil is likely to be affected by erosion already, at a slope of 3% it may be assumed that approximately 84% of the area is subjected to intensive erosion. The intensity depends on constant as well as seasonal factors. It may thus be written:

$$N\{G, J, U, R, H\} \quad (2)$$

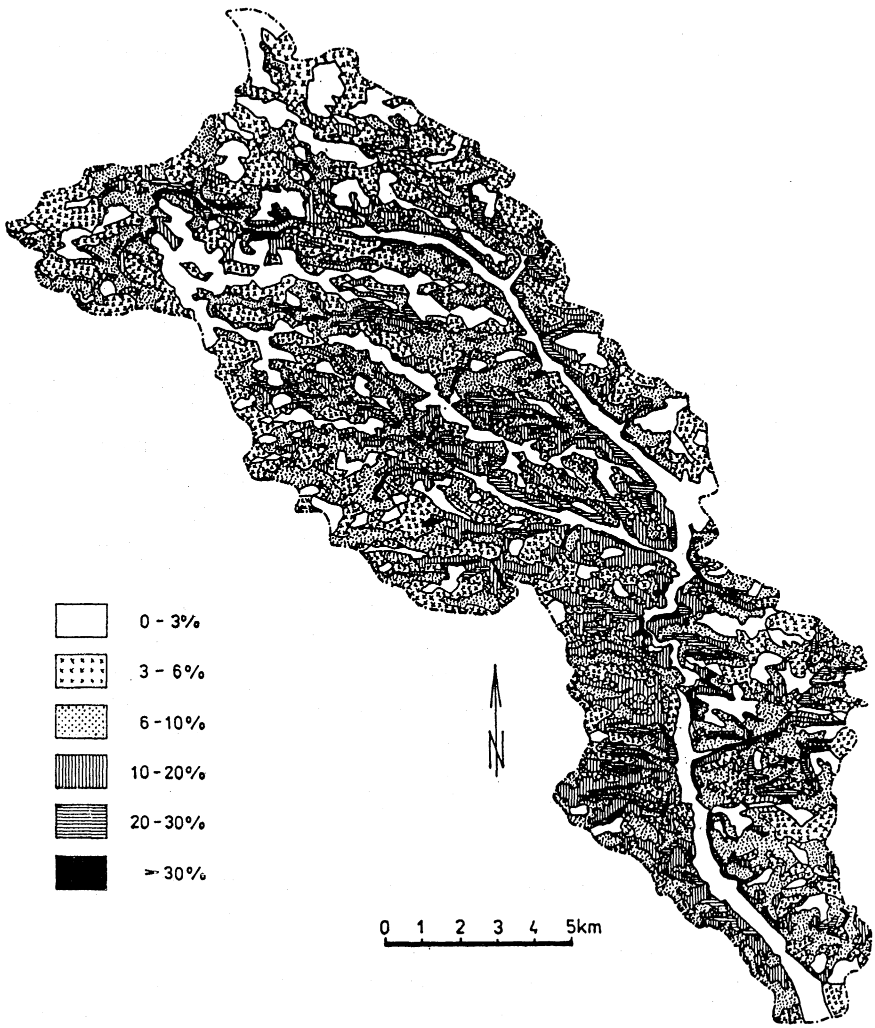

Fig. 1 Map of gradients of the River Dlubnia basin.

where:
N = intensity of erosion processes,
G = geological structure and kind of depth,
I = gradient of inclination,

Table 2 Land use in the Dlubnia River basin.

Land use	Area: (km^2)	(%)
Forest	20.6	9.5
Grassland	3.5	1.6
Cropland	170.3	78.1
Other	23.7	10.8

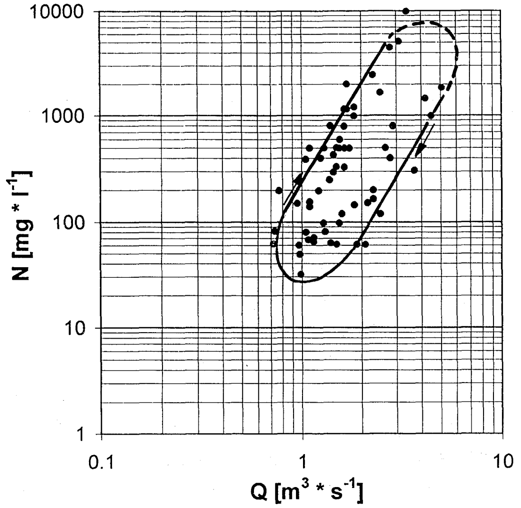

Fig. 2 Function N = f(Q)—season of spring thaw.

U = agricultural use,
R = degree of development of flora,
H = meteorological conditions of which the most important are: quantity and intensity of precipitation, intensity of thaws etc.

Seasonal hydrological-meteorological factors that were considered separately were: spring thaws, summer rainfalls, autumn low falls and winter snowfall. Due to complex meteorological factors the duration of each of these seasons was differed each year. The relationship $N = f(Q)$ plotted for each season depicts clearly the investigated phenomenon in the form of a loop. Figure 2 shows this loop for the spring rainfall season.

A special role in load transport is played by flood surges. For the same rate of flow the suspended load is much greater during the rising stage of a flood than during the recession. The broken line in the diagrams shows the hypothetical traces of the loop in periods of high flow. The elaborated diagrams ensured that the quantity of water turbidity on days when no observations where performed could be established and subsequently allowed for calculations of the whole mass of the material transported during the investigation period to be performed. The calculation results are show in Table 3. The annual mean load transported is 47.9 t km^{-2} $year^{-1}$. This amount enters the reservoir thus contributing to its siltation.

MASS OF THE TRANSPORTED LOAD ASSESSED BY USING THE MUSLE METHOD

An evaluation of the sediment load carried in the investigated basin use was undertaken using the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975) elaborated on the basis of the Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1965). This equation takes the form:

$$E = R \cdot K \cdot L \cdot S \cdot C \cdot P \qquad (3)$$

where:

E = the mean from a couple of years of annual eroded soil mass from a unit of surface area,
R = annual mean erosion from rainfall and runoff,
K = coefficient of erodibility,
L = nondimensional coefficient of slope length,
S = nondimensional coefficient of slope gradient,
C = nondimensional coefficient of type of cropping and land use,
P = nondimensional coefficient of erosion control practice.

The value of the coefficient of soil erodibility to erosion K is influenced, according to the USLE method, mainly by granulation characterized by the percentage of three grain-size fractions in the soil layer: (a) <0.002 mm, (b) 0.002–0.1 mm, (c) 0.1–2.0 mm, and content of humus in the top layer. The range of soils in the basins was determined from maps of at 1:300 000 scale. Granulation of the top layer and the humus content was adopted from typical profiles for a given soil (*Album gleb Polski*, 1986). The coefficient of length L and slope gradient S, called the topographic coefficient, were obtained from a nomogram in Wischmeier & Smith

Table 3 The total sediment load in the years 1966–1991: River Dlubnia—cross-section Zeslawice.

Year	Suspended load: Volume (m^3)	Mass (t)
1966	22 244.6	15 889.0
1967	32 484.0	23 203.3
1968	9 117.7	6 512.6
1969	97 646.7	69 961.4
1970	52 516.9	37 512.0
1971	11 659.2	8 328.0
1972	10 169.5	7 263.9
1973	952.0	680.0
1974	2 052.7	1 466.2
1975	22 466.7	16 047.6
1976	3 213.4	2 295.3
1977	15 080.7	10 771.9
1978	3 902.7	2 737.6
1979	5 692.6	4 066.1
1980	4 839.6	3 456.8
1981	1 549.9	1 107.1
1982	3 111.5	2 508.2
1983	1 024.2	731.5
1984–1886	no observations	no observations
1987	9 053.0	6 463.8
1988	4 878.1	3 482.9
1989	6 670.3	4 762.6
1990	681.8	486.8
1991 (I–X)	701.4	500.8
Total	321 809.8	240 235.3
Mean	13 991.5	10 445.0

(1978). The slope length was determined as the relationship of the basin area and double length of water flows. Gradients of the basin were established from topographical maps at 1:25 000 scale.

The coefficient of cropping and land use *C*, expressing the reduction of erosion as a result of vegetation cover, is the relation of soil loss and cultivation of given plants in a determined way to the losses which would occur from bare fallow land. The protective capacity of plants changes with their development, so the value of the coefficient *C* changes as well, and erosion depends also on the time of occurrence of the rainfall event which causes it. The coefficient of anti-erosion activities *P* is the relation of soil loss on the application of treatments diminishing erosion intensity to losses from pattern fields (cultivated along the slope). Cultivation along contour lines, stripes of swards parallel to contour lines, and other treatments should be included as protective activities. The established annual mean values of this coefficient depend also on the gradient length of slopes, kind of soil, kind of cultivation etc. (Banasik & Madeyski, 1990)

The mean mass of eroded load transported from the basin was determined as 66.9 t km^{-2} $year^{-1}$.

CONCLUSIONS

The loess soil in the basin and its improper management, especially ploughing along the slope, are conducive to intensive erosion. The great variability of the erosion processes is reflected in the water turbidity which varied in the period under investigation from 10 to 24 000 mg l^{-1} (10 April 1972).

It follows from investigations that the highest intensity of erosive processes occurs during the spring thaws when heavy rains occur and there is a lack of vegetation cover in the basin. An attempt to evaluate the quantity of erosion in a loess basin was undertaken by means of the soil loss equation. There was a discrepancy between the calculated results and those obtained by direct measurements of turbidity. The measured value was 44.9 t km^{-2} $year^{-1}$, whereas, by means of the MUSLE method it was 66.9 t km^{-2} $year^{-1}$. Reasons for this discrepancy can be explained by the fact that precise determination of all the factors of the MUSLE is very difficult. Especially difficult are those factors which vary periodically (kind and area of cultivation, succession of crop rotation, erosive power of rainfall).

Besides, not all the sediment load eroded from the basin enters the rivers. Considering the fact that turbidity measurements are also charged with a certain error, the MUSLE method, with a proper choice of its parameters, can also be used in loess basins. This is of significant importance in predicting the silting up of reservoirs.

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