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Estimation of water erosion threat of the Smuga stream basin in the Beskid Wyspowy

Ocena zagrożenia erozją wodną zlewni potoku Smuga w Beskidzie Wyspowym

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Słowa kluczowe: erozja wodna, model USLE, GIS

Abstract
In this work, results of evaluation of potential water erosion threat of the Smuga stream basin in Beskid Wyspowy were presented according to the USLE model and the GIS techniques. The basin area is 5.40 km^2; mean height is 636.4 m a.s.l. and mean basin slope is 21.32%. The basin is in a significant part covered by forest which is 54.26%, grasslands occupy 8.15% and arable lands 34.63%. The highest water erosion threat takes place on arable lands with high slopes and defective cultivation. Calculated soil loss is 2078.59 Mg yearly, which gives a unitary loss of 3.85 Mg for 1 ha. This classifies the investigated basin as very low threatened – second class in sixth degree scale.

Streszczenie
W pracy przedstawiono ocenę potencjalnego zagrożenia erozją wodną zlewni potoku Smuga w Beskidzie Wyspowym, według modelu USLE i technik GIS. Powierzchnia zlewni ma 5,40 km^2. Średnia wysokość zlewni wynosi 636,4 m npm, a średni spadek zlewni 21,32%. Jest zlewnią w znacznej części porośniętą lasem – 54,26%, użytki zielone stanowią 8,15 %, natomiast grunty orne – 34,63%. Największe zagrożenie erozją wodną występuje na gruntach ornych, o dużych spadkach i wadliwej uprawie. Potencjalna wielkość ubytku masy glebowej w zlewni wynosi 2009,54 Mg rocznie, w przeliczeniu na 1 ha 3,35 Mg, daje to II klasę – małe zagrożenie, w 6-stopniowej skali zagrożenia erozją wodną.

1. INTRODUCTION

Water erosion is a natural process modifying Earth surface. Apart from surface destruction, erosion causes loss of upper soil layer, deterioration of water quality and silting of water constructions. Evaluation of erosion threat has high significance in many fields of engineering and economics. There are many methods for the investigation of erosion intensity. Nowadays, together with the development of computer techniques, one can observe an excellent evolution of modelling methods. The next qualitative step in the investigation and evaluation of erosion phenomena is connected with GIS (Geographic Information System) techniques and easier access to them. The aim of the work was evaluation of erosion threat of the mountainous basin of the Smuga stream of agricultural use, which may be seen as an illustrative case study. The evaluation was carried out by means of the USLE (Universal Soil Loss Equation) model with parameters estimated using GIS techniques.

2. OBJECT

The investigated basin is in the Beskid Wyspowy – the Western Carpathians. After Gumiński (1948), the area belongs to the podkarpacka agriculture-climatic district. Growing season lasts 200–220 days. Field works begin in first decade of March. Annual sum of precipitation amounts to between 800 and 1000 mm. The highest amount of precipitation occurs from May to September, which is a monthly average above 90 mm. Mean annual amount of days with precipitation above 10 mm amount to 22–24. Beginning of snow melt occurs between 1 and 5 of March. Growing season starts on an average between 5 and 10 of April. Winter (days with temperatures above 0°C) appears between 30 November and 5 December. Snow cover remains for 80–90 days during the year (Atlas Klimatu Polski 2005).

The Smuga stream basin is a part of the Lubieńka basin, left tributary of Raba. The area of the basin is 5.40 km^2. It is a little elongated and fairly stocked. Basin length amounts to 3.08 km, breadth 1.75 km, and perimeter 10.85 km. The mean height is 636.4 m a.s.l. The highest point is 857.9 while the lowest one 415.0 m a.s.l. The length of main stream amounts to 4.42 km and slope 6.22%. The density of river network is 2.43 km•km^{-2}. The basin is characterised by very advantageous distribution of forests. Forests occupy the upper parts of the basin (Ryczek 2011).

3. MATERIALS AND METHODS

USLE is the most known worldwide as the model for water erosion intensity estimation. The basic equation is (Wischmeier and Smith 1978):

$$E = R \cdot K \cdot L \cdot S \cdot C \cdot P \ [\mathrm{Mg \cdot ha^{-1} \cdot year^{-1}}]$$

where:
- R – rainfall erosivity factor [EU = MJ•cm•ha^{-1}•h^{-1}]
- K – soil erodibility factor [Mg•ha^{-1}•EU]
- L – slope length factor [-]
- S – slope steepness factor [-]
- C – cropping management factor [-]
- P – conservation practices factor [-].

There are many methods for the determination of equation factors. In this work, the GIS techniques were used for their estimation. Distribution and values of factors were determined by elaborated topic overlays (Fig. 1) and creating homogeneous areas. The following topic overlays were used:

- steepness, worked out using Digital Elevation, of raster resolution 50 m
- land use structure, based upon orthophotomaps from panchromatic satellite picture IRS
- textural groups, using digital soil map.

Topic overlays were worked out by means of the following computer programs:

- MapInfoProfessional SCP release 8.0
- Surfer release 8.0.

Rainfall erosivity factor (R) was calculated based upon Fourier's ratio in Arnoulds' (1977) modification. This ratio is quite well correlated with R factor (Licznar 2005, Laureiro and Coutinho 1995). Fourier's ratio was calculated as a mean from multiyear period 2002–2011 from the nearest precipitation station, from the equation:

$$F = \frac{1}{m} \cdot \sum_{j=1}^{m} \sum_{i=1}^{12} \frac{p_{i,j}^2}{P_j} \ [\mathrm{mm}]$$

where:
m – number of years in multiyear period
$p_{i,j}$ – monthly sum of precipitation in i-th month and j-th year [mm]
P_j – yearly sum of precipitation in j-th year [mm].

Based upon Fourier's ratio, the rainfall erosivity factor (R) was determined by multiplication of this ratio by 1.702, adapting to unit Je [MJ•cm•ha^{-1}•h^{-1}] (Renard et al. 1996).
Soil erodibility factor (K) was estimated according to Renard et al. (1997):

$$K = 0.0034 + 0.0405 \cdot \exp\left[-0.5\left(\frac{\log D_g + 1.659}{0.7101}\right)^2\right] [\mathrm{Mg \cdot ha^{-1} \cdot Je^{-1}}]$$

where:

$$D_g = \exp\left(0.01 \cdot \sum f_i \cdot \ln \frac{d_i + d_{i-1}}{2}\right),$$

d_i – upper limit of interval in i-th fraction class [mm]
d_{i-1} – lower limit of interval in i-th fraction class [mm]
f – content of i-th fraction [%].

Dg was determined based upon texture measurement according to PN-R-04032. Granular groups were classified according to Polish Soil Science Society (PTG 2008). Mean factor for the basin was determined using topic overlay soil species.

Factor L was determined after Moore et al. (1993):

$$L = 1.4 \cdot \left(\frac{A_s}{22.13}\right)^{0,4}$$

where:
A_s – upslope drainage specific area.

Factor S was determined using equation:

$$S = 65.4 \cdot \sin^2\theta + 4.56 \cdot \sin\theta + 0.0654 \ [\text{-}]$$

where:
θ – slope angle [%].

Factors L and S were determined using Digital Elevation Model.
The values of cropping management factor (C) were taken after Koreleski (1992) – for spring oat: 0.104; spring barley – 0.124; potatoes – 0.229; grasslands – 0.015; forests – 0.002; built areas – 0; and weighted mean for the whole basin area was determined based upon topic overlays land use and orthophotomaps.
The conservation practices factor (P) was taken after Koreleski (1992). Tillage along and slantwise contours tillage were 1.0 while crosswise contours tillage was 0.5–1.0. Tillage directions were determined based on topic overlays land use and orthophotomaps.

4. RESULTS AND DISCUSSION

Factor R
Value for the whole basin calculated as a mean value for 10 years amounted to 183.653 EU. Standard deviation attained was 16.065 EU. In Polish literature, there is little information concerning both the value and methods for R determination. Lorenc (1985) elaborated a map of spatial distribution of rainfall erosivity factor in Poland based on Fourier's ratio. Józefaciuk and Józefaciuk (1995) as well as Górski and Banasik (1992) elaborated on the R factor distribution for south-eastern Poland. Other works are connected with single stations.

Factor K
Regarding texture, the soil of the investigated basin is characterised by low differentiation. The largest area, mainly northern part of the basin, is occupied by loam soil. The lower area is covered by sandy clay loam soil, occurring in the southern part. On small areas of the eastern and southern parts, clay loam, silt loam and sandy loam soil are present. Mean values of K factor fluctuated between 0.141 and 0.430 Mg•ha^{-1}•EU^{-1} (Table 1). Weighted mean for the whole watershed were determined according to percentage distribution of granular groups and determinations of texture amounted to 0.339 Mg•ha^{-1}•EU^{-1}. Taking into account the fact that K factor is little differentiated, this value was taken as characteristic for the whole watershed area.

Table 1. Percentage share of textural groups in basin and calculation of K factor mean values

Textural group according to PTG 2008	Area [km^2]	Share in basin [%]	Mean value for group [Mg•ha^{-1}•EU^{-1}]
Clay loam	0.20	3.71	0.141
Silt loam	0.35	6.48	0.430
Sandy loam	0.02	0.37	0.354
Sandy clay loam	1.41	26.11	0.279
Loam	3.42	63.33	0.248
Total	5.40	100.00	-

*Klasyfikacja uziarnienia gleb i utworów mineralnych – PTG (2008)

Factors L and S

In the watershed, slopes above 27% prevail. They occupy 38.89% of the whole area. Considerably of less percentage are the lowest slopes, below 5% (1.30%) (Table 2). Mean basin slope is 21.32%. Regarding rectilinear of slopes, their heterogeneity was not taken into consideration. Four homogeneous regions were distinguished considering LS ratio. In the first region LS attained 0.145, in the second 0.578, in the third 1.425 and in the fourth 4.115. Region IV covers the largest area (38.89%).

Factor C

In the structure of land use, forests prevail with a cover of 54.26%, arable lands 34.63% and grasslands 8.15%. The rest is occupied by built areas. On arable lands, according to orthophotomaps, spring oat occupied 42%, spring barley 39% and potatoes 19% (Table 3).

Factor P

In the watershed, slantwise contours tillage prevails. When the mean watershed slope (21.32 %) is taken into account, the value was taken as equal to 1.0.

Calculation of potential water erosion

After overlaying topic layers (Fig. 1) connected with the following factors, 24 homogeneous regions of the same values of unitary water erosion intensity were obtained (Fig. 2). Potential unitary soil loss from homogeneous regions was in the range from 0.458 to 43.457 $Mg \cdot ha^{-1} \cdot y^{-1}$. Calculated unitary erosion intensities were classified according to Marks et al. (1989) sixth degree scale. The scale distinguishes six classes of water erosion intensity in $Mg \cdot ha^{-1} \cdot y^{-1}$: I (lack of erosion <1), II (very low 1–5), III (low 5–10), IV (mean 10–15), V (high 15–30) and VI (very high >30). In the investigated basin, the largest areas were not threatened by erosion. They are occupied by forests and grasslands. Almost 23% of the area is occupied by areas threatened by low erosion intensity. Total potential yearly soil loss from the whole basin area is 2078.59 Mg, which gives a value of 3.85 Mg from 1 ha (Table 4). This enables the classification of the investigated basin as low threatened by erosion (II class).

5. CONCLUSIONS

1. The calculated unitary soil loss from 1 ha is 3.85 Mg, which classifies the investigated basin as very low threatened. It is connected with advantageous distribution of forests and proper management.
2. More than 23% of the total area of the investigated basin does not show an erosion threat.
3. GIS techniques may be essential tools for further development of model USLE. Particular attention should be paid on factor LS, which is characterised by the highest differentiation in the basin scale.

Table 2. Distribution of slopes in the Smuga stream basin and homogeneous regions of LS parameter

Slopes interval [%]	Area [km^2]	Share in basin [%]	Homogeneous region	Area [km^2]	Share in basin [%]	LS value [-]
<5	0.07	1.30	I	0.65	12.04	0.145
5–10	0.58	10.74				
10–18	1.37	25.37	II	1.37	25.37	0.578
18–27	1.28	23.70	III	1.28	23.70	1.425
>27	2.10	38.89	IV	2.10	38.89	4.115
Total	5.40	100.00	-	5.40	100.00	-

Table 3. Structure of land use for the Smuga stream basin

Land use		Area [km^2]	Share in basin [%]	Value of C parameter [-]
Arable lands	Spring oat	0.79	14.54	0.104
	Spring barley	0.73	13.51	0.124
	Potatoes	0.35	6.58	0.229
Grasslands		0.44	8.15	0.015
Forests		2.93	54.26	0.002
Built areas		0.16	2.96	0
Total		5.40	100.00	-

Table 4. Calculation of water erosion intensity

Class*	Share		Mean unitary water erosion intensity		Total water erosion intensity
	%	Km^2	($Mg \cdot ha^{-1} \cdot rok^{-1}$)	($Mg \cdot km^2 \cdot rok^{-1}$)	($Mg \cdot rok^{-1}$)
I	63.33	3.42	0.458	45.8	156.64
II	22.59	1.22	2.636	263.6	321.59
III	4.82	0.26	8.847	884.7	230.02
IV	3.15	0.17	12.114	1211.4	205.94
V	2.78	0.15	25.478	2547.8	382.17
VI	3.33	0.18	43.457	4345.7	782.23
Total	100.00	5.40	-	-	2078.59

*Water erosion threat classes according to Marks et al. (1989).

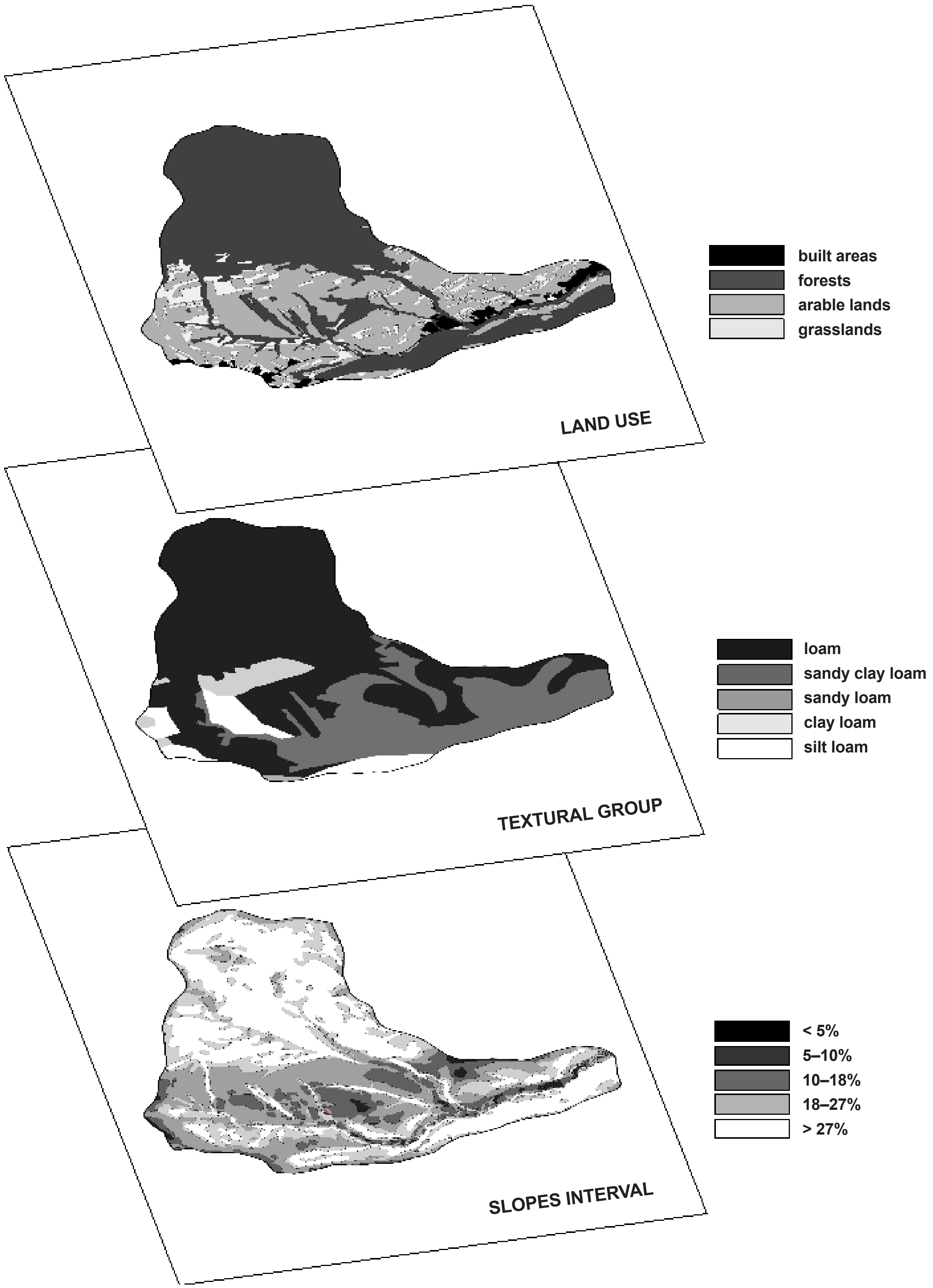

Fig. 1. Chosen topic overlays for the Smuga stream basin

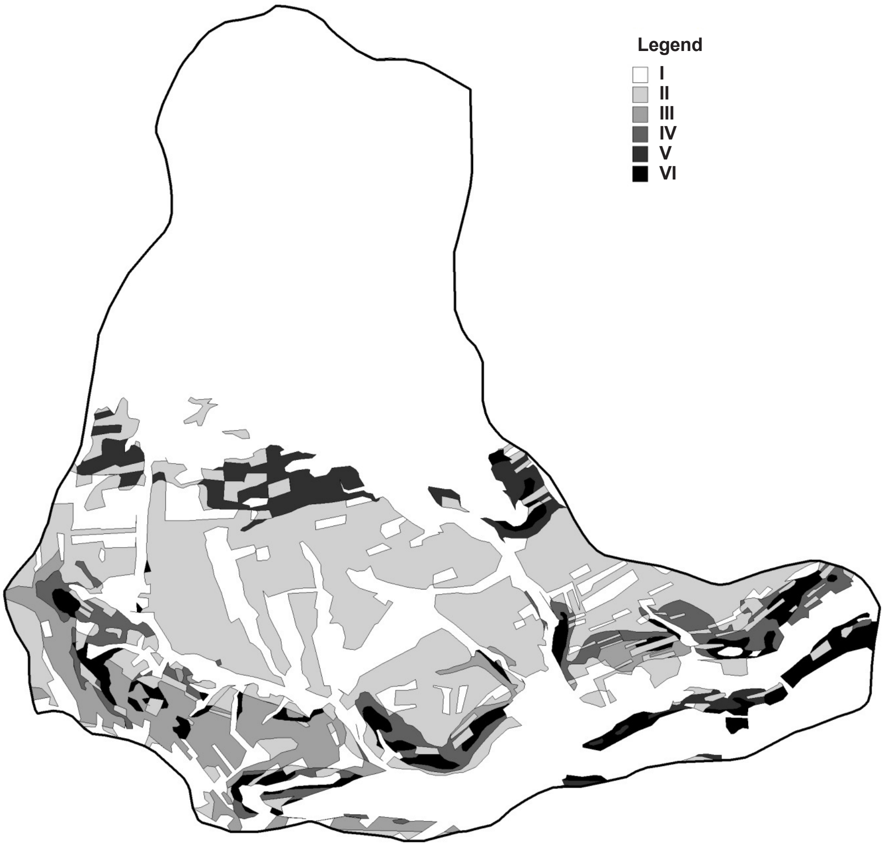

Fig. 2. Distribution of potential threats of water erosion classes in the Smuga stream basin

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