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IMPACT OF LAND USE CHANGES ON SOIL EROSION AND DEPOSITION IN A SMALL POLISH CARPATHIANS CATCHMENT IN LAST 40 YEARS

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Abstract: Over the last 40 years, many changes have been observed in the catchment in Polish Carpathians in terms of land use, i.e., a decrease in arable land area (from 48% in 1969 to 14% in 2010) and an increase in grasslands area (from 3% in 1969 to 30% in 2010). These changes have been resulted primarily from socio-economic transformations in Poland, after 1989. In this study, two models (RUSLE and USPED) were used to determine erosion and deposition processes in the small Carpathian catchment (Bystrzanka catchment, 13 km^2) in 4 different time periods associated with different land use. The area of arable land where a high risk of erosion was recorded amounted to 47% in 1969, and in 2003, it was 30% lower in the RUSLE model and 13% lower in the USPED model. Moreover, a percentage increase in grasslands (meadows) and decrease in arable land on which deposition was recorded was also observed. This is directly associated with a change in land use. The average value of erosion estimated in the catchment area decreased from 8.27 t•ha^{-1} in 1969 to 2.89 t·ha^{-1} in 2003 in relation to land use and reduction in the area occupied by arable land. The values obtained as a result of erosion size modelling are similar to the measurements conducted in the experimental plots in Research Station in Szymbark.

Key words: land use changes, soil erosion, deposition, modelling, RUSLE, USPED, Bystrzanka catchment, Polish Carpathians

1. INTRODUCTION

In the past several dozen years, we have observed changes in land use which considerably affect the development of the natural environment. This process intensified in the period of the economic transformation when socio-economic changes led to the outflow of people from rural areas. Prior to 1931, agricultural land dominated in the structure of the Low Beskid Mountains. However, it decreased to 37% in 1988. Moreover, at the end of the 20th century, an increase in the forestation proportions from 30% to 60% was observed (Soja, 2012). A similar situation occurs in the region of the Gorce Mountains where a marked decrease in the share of arable land and meadows as well as a simultaneous increase in forests may be observed (Bucała, 2014). The changes in the Carpathians correspond to those observed in other mountainous regions in Europe (MacDonald et al., 2000; Lipský, 2001; Bakker et al., 2005; Falcucci et al., 2007). The manner of land use is of key importance in the process of slope denudation (Święchowicz, 2002; Van Rompaey et al., 2002). It also influences the process of freshet wave formation and the amount of material transported (Kijowska & Bochenek, 2011).

Slopes are also modelled by the processes of soil washing and deposition. Precipitation of high sum and intensity leads to abrupt and considerable geomorphological changes in slopes and channel. In such a situation, the threshold values are exceeded and the equilibrium of the geoecosystem is disturbed. Soil particles detached due to rain drops move down the slope and are the main source of material carried with the surface runoff (Salles & Poesen, 2000). The size of soil wash processes depends, among others, on the amount and velocity of water flowing down the slope, soil resistance to erosive factors, slope gradient, human activity (e.g. agrotechnical procedures), and above all, land use (Gil, 2009; Święchowicz, 2002; Latocha & Migoń, 2006). The greatest soil downwash are observed during heavy and intensive precipitation. Areas used for agricultural purposes react to precipitation very quickly, but the soil wash process rarely occurs simultaneously on all slopes of a catchment area. Its intensity varies along the horizontal profile of the slope.

A risk of water erosion applies to approximately 29% of the area in Poland and the average annual rate of soil loss amounts to approximately 76 $t·km^{-2}$ (Jadczyszyn et al. 2003), but the values range from 2.7 to 280 $t·km^{-2}·year^{-1}$ (Maruszczak, 1991). According to Maruszczak (1991), the average annual soil loss in the Flysch Carpathians amounts to approximately 280 $t·km^{-2}$.

Modelling slope processes is an integral element of contemporary methods used in geomorphological studies (Mati et al., 2006; Smith et al., 2010). The development of techniques used for acquiring, processing and analysing spatial data enables simulations of erosion and deposition processes to be conducted on areas that are used in various ways. There are numerous models based on which the size of erosion or deposition may be estimated. They include: RUSLE (Revised Universal Soil Loss Equation) (Wischmeier & Smith, 1978), WEPP (Water Erosion Prediction Program), (Laflen et al., 1991), USPED (Unit Stream Power-based Erosion Deposition) and SIMWE (Simulation of Water Erosion) (Mitasova et al., 1998).

The aim of this paper is to analyse the size of soil erosion and deposition processes in a small Carpathian catchment (Bystrzanka catchment) in the face of changes in land use that occurred between 1969 and 2010 with the use of two models: Revised Universal Soil Loss Equation (RUSLE) (Wischmeier & Smith, 1978) and Unit Stream Power-based Erosion Deposition (USPED) (Moore & Burch, 1986; Mitasova et al., 1998). The results obtained allow erosion and deposition areas to be indicated and enable estimation of the size of erosion that occurred between 1970 and 2010 as well as identification of differences between RUSLE and USPED models.

2. STUDY AREA

In the region of the Bystrzanka catchment, the Research Station of the Institute of Geography and Spatial Organization of the Polish Academy of Sciences (IG&SO PAS) has been operating since 1965. The investigations of slope processes, such as surface runoff, subsurface runoff and soil wash, started at this site in 1968 on experimental slopes with different types of land use (Gil & Słupik, 1972). Thus, this area has rich literature that is essential for proper modelling of soil erosion and deposition processes. The study area is situated in the Polish Flysch Carpathians at the border of two physico-geographical units: the Carpathian Foothills and the Low Beskid Mountains (Starkel, 1972). The Bystrzanka catchment occupies the area of 13 km^2 and is situated at the altitude of 300-753 m above sea level (Fig. 1). The Beskid part (500-752 m above sea level) is composed of resistant Oligocene sandstone of Magura type. The Foothill part (the left part) of the catchment rises to the altitude of 400-450 m above sea level and is made up mainly of shale sandstone of Inoceramus beds (the Paleocene). An average slope gradient in the catchment is 10˚. The predominant type of soil in the Bystrzanka catchment is brown soil which developed on medium and heavy loam with relatively low water retention capacity. The thickness of weathered material on slopes with a considerable share of a rocky fraction amounts to several meters.

The most favourable conditions for soil wash are observed in the summer months of the water year, particularly at the turn of the calendar spring and summer. This is associated with considerably intensive and heavy rainfall and the lack or slight amount of vegetation on arable lands (Gil, 2009). For the purposes of erosion and deposition modelling, we used the pluviographic records obtained in the Research Station in Szymbark in the summer season (May-October) of the hydrological years 1969-2010. In this period, the average precipitation sum in the summer season amounted to 561.8 mm. It was characterised by high variability: from 857.2 mm (1980) to 287 mm (1982). A rainfall event of the highest intensity of 6.3 $mm·min^{-1}$ was recorded in August 2002. The event lasted 3 hours and the rainfall sum amounted to 52 mm.

3. METHODS

The modelling of changes in the size of erosion and deposition in the Bystrzanka catchment was conducted for diversified land cover and land use types in 1969, 1986, 1997 and 2003. Each simulation was based on a given land cover and land use type. For the period of 1970-1980, 1990-2000 and 2000-2010, the land use map drafted by Gil (1979) and Olędzki (2011) were used. The land use map from the 1980s was created on the basis of a satellite image of the Landsat 5TM from August 1986 with the resolution of 30m x 30m.

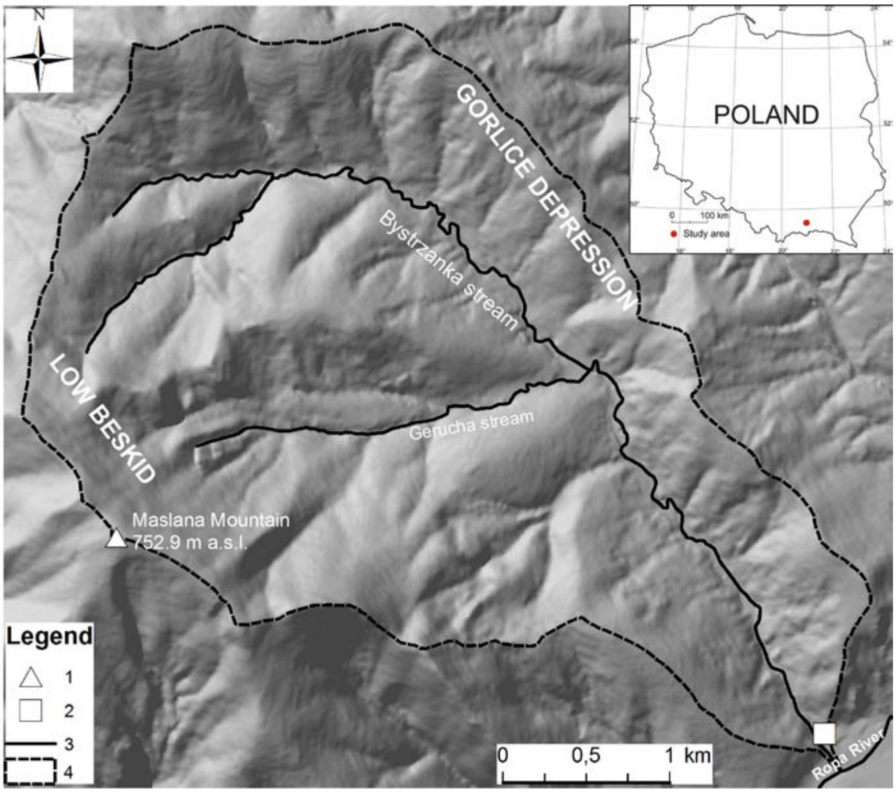

Figure 1. Research area (1-the highest point in the catchment, 2-Research Station in Szymbark IG&SO PAS, 3-stream, 4-catchment boundary)

The TM scanner (Thematic Mapper) of the Landsat 5 satellite registers radiation reflected in six ranges of visible spectrum, near and mid-infrared and far thermal infrared radiation. The image was not, however, sufficiently precise. The land use map from 1986 served merely as additional information, and values concerning erosion and deposition at that time are solely approximate.

In order to determine erosion and deposition of material, two models were used: RUSLE, (Wischmeier & Smith, 1978; Renard et al., 1991, 1997), (1.) and USPED (Moore & Burch 1986). The RUSLE model assumes that erosion mainly depends on the sum, duration and intensity of precipitation whereas the USPED model assumes that erosion not only depends on precipitation, but also on the ability to transport sediments with the surface runoff (Mitasova et al., 1998). The results obtained with the use of the USLE model merely show the soil erosion rate and should be understood as the maximum erosion possible in a given region in given conditions where soil deposition is not taken into account (Mitasova et al., 1999). The main assumption of the UPSED model concerns limited amount of soil material that may be transported with flowing water. Therefore, according to the authors, using both RUSLE and USPED models appears to be the best solution in determining the intensity of erosion and deposition in the conditions of diverse land cover and land use types. The soil loss in the RUSLE model is estimated based on the following equation:

$$(1.)\ E = R \cdot K \cdot L \cdot S \cdot C \cdot P$$

where:

E - annual amount of eroded soil per the area unit ($t \cdot ha^{-1}$); R - rainfall and runoff erosivity factor for a given localisation [($MJ \cdot ha^{-1}$) ($mm \cdot h^{-1}$)]; K - soil erodibility factor - its susceptibility to washing [($t \cdot ha^{-1}$)/($MJ \cdot ha^{-1}$)($mm \cdot h^{-1}$)]; LS - the topographical factor determining the length and gradient of the slope (dimensionless); C - vegetation factor (dimensionless); P - anti-erosion practice factor (dimensionless).

The transporting ability is calculated with the use of energy function of the slope, water runoff, type of soil and land use. The USPED model is based on similar coefficients (R- rainfall and runoff erosivity factor; K - soil erodibility factor; C - vegetation factor; P - anti-erosion practice factor), but the LS index (2.) is replaced with a T index calculated as:

$$(2.)\ LS = T = A^{m} (\sin \beta)^{n}$$

A - unit of the contributing area ($m \cdot m^{-2}$); β – gradient (°); n, m are coefficients that depend on the type of water erosion

4. RESULTS

4.1. Changes in land use between 1969 and 2010

In 1969, the land cover and land use in the Bystrzanka catchment area were highly diversified. It was associated with the natural topography, gradient of slopes and relative altitudes. At that time, arable land was predominant (48%) and forest area constituted 36% of the catchment area (Fig. 2). Over the years, a marked decrease in the amount of arable land was observed: by 18% in 1997, by 29% in 2003 and by 34% in 2010 compared to 1969. As for meadows and pastures, an increase in the area was observed by: 16%, 25% and 27% respectively (Kijowska-Strugała, 2015). The proportion of land on which potatoes were cultivated decreased from 10% (1969) to 5% (2003). The cereal cultivation area also decreased from 28% to 12%. Slight changes are also observed in afforested areas. They are gradually increasing. A decrease in arable area mainly resulted from structural and spatial as well as economic transformation that followed the Polish political transformation in 1989. A reduction in agricultural production led to a decrease in the area used for this purpose. These changes were mainly associated with an unfavourable economic situation for farmers and with problems that resulted from the lack of sales of agricultural produce. The purpose of the structural funds of the European Union was at first to support low-budget manufacturers, which led to relinquishing agricultural land use and, for instance, forestation of arable areas (Bucała, 2014).

The processes of erosion and deposition are largely influenced by steepness. The higher the slope gradient, the higher the probability of erosion. This is associated with the velocity and size of the surface runoff. The dominant slope gradient in the Bystrzanka catchment area is 5-15˚ and such slopes constitute 78% of the whole area. In order to determine correlations between land use and slope gradient, land use maps from different time periods were compared with the slope steepness map generated based on a digital elevation model. In all gradient ranges, a decrease in the land used for agricultural purposes was observed. The highest share of arable area was observed in the 5-10˚ group (Table 1). Having compared the land use from 1969 and 2010, it was concluded that the largest percentage loss in arable land occurred on slopes with the steepness that exceeded 15˚ (by more than 90%). With the growth of the gradient slope, decrease the arable area, but increase the afforested area. In 1969 and 1986, the highest share of forests was observed in the 10-15˚ gradient range, but in 1997 and 2003, it was observed in the 5-10˚ group. In 2003, the largest increase in afforested areas, as compared to the land use of 1969, was noted in the 5-10˚ group (increase by 30%). A similar situation refers to grasslands where the increase observed in the 5-10˚ group amounted to as much as 180%, i.e. approximately 3 km^2.

4.2. Erosion and deposition in the catchment

The results of erosion and deposition simulations with the use of RUSLE and USPED models for 4 different rainfall erosivity coefficients, depending on land use and in different time periods are presented in figure 3. The results of the modelling vary. This is mainly caused by deposition areas (USPED) that are not included in the RUSLE model.

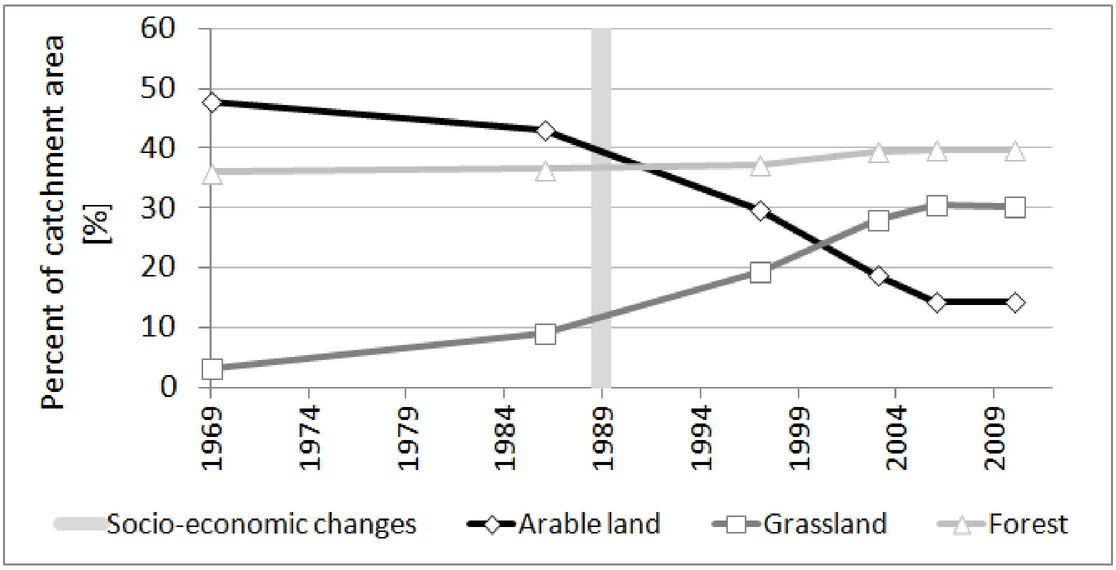

Figure 2. Land use changes in the Bystrzanka catchment in the period 1969-2010

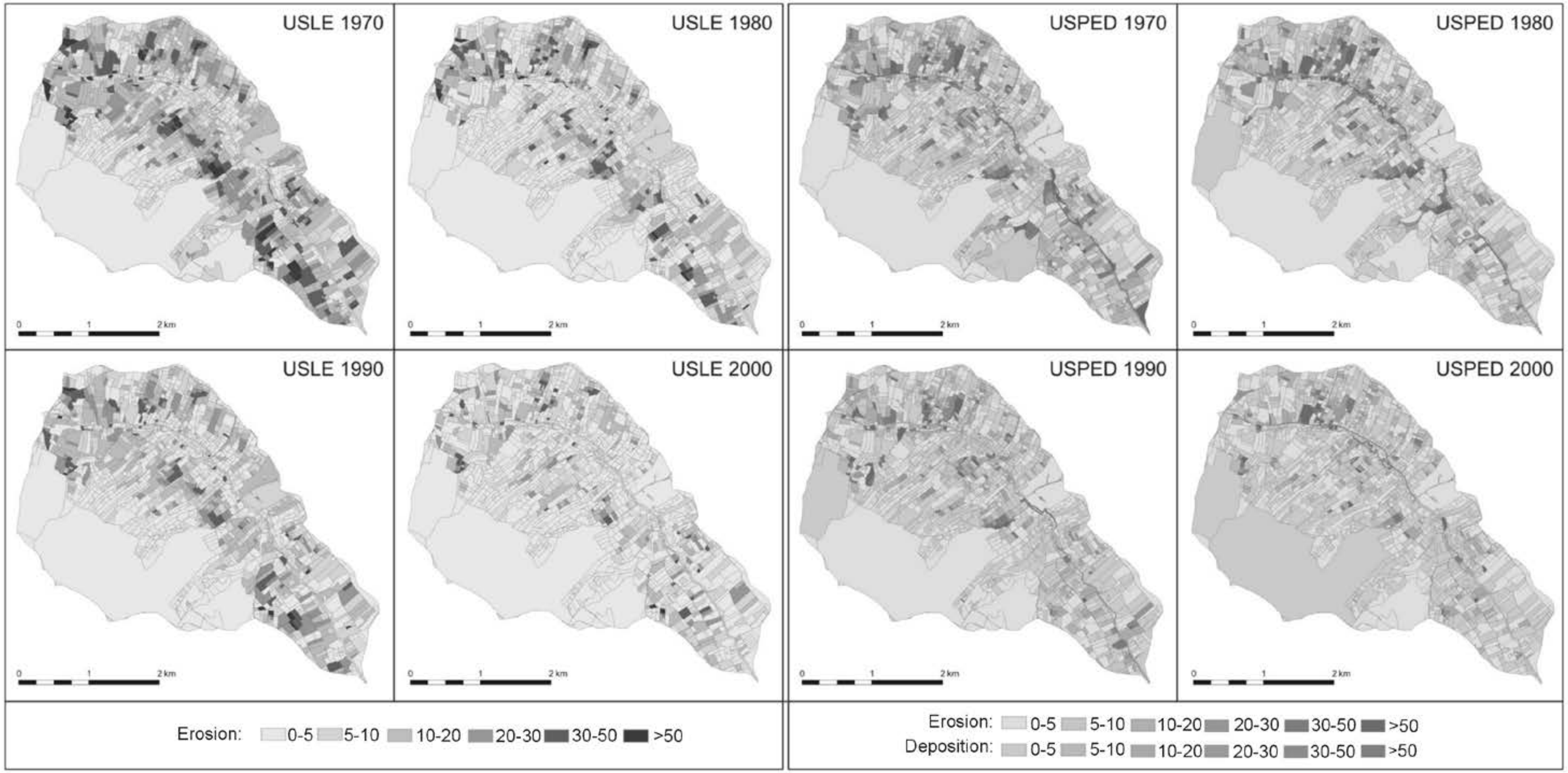

Figure 3. The result of erosion (USLE, USPED) and accumulation modeling (USPED) in the Bystrzanka catchment at defined classes [$t \cdot ha^{-1} \cdot km^{-2}$]. Data include 1970s, 1980s, 1990s and period 2000-2005 with a different land use, total precipitation, rainfall and runoff erosivity factor.

Table 1. Percentage of land use forms in different classes of gradients in Bystrzanka catchment

Gradient [°]	Land use	1969	1986	1997	2003	2010
<5	Arable land	3.96	1.93	2.96	1.77	1.56
	Grassland	1.74	3.63	2.11	3.29	3.43
	Forest	3.13	3.24	3.76	3.78	3.72
5-10	Arable land	27.18	15.10	18.24	10.94	9.67
	Grassland	7.07	17.74	12.19	19.58	21.62
	Forest	12.51	13.93	16.32	16.24	15.40
10-15	Arable land	14.48	7.75	7.95	4.19	3.56
	Grassland	4.30	9.71	8.25	11.72	12.34
	Forest	12.70	14.04	15.28	15.57	15.69
15-20	Arable land	1.44	0.64	0.40	0.15	0.13
	Grassland	0.55	0.92	0.99	1.17	1.18
	Forest	6.79	7.23	7.39	7.46	7.53
20-25	Arable land	0.09	0.02	0.01	0.00	0.00
	Grassland	0.04	0.09	0.05	0.05	0.05
	Forest	3.21	3.22	3.27	3.28	3.31
25-30	Arable land	0.00	0.00	0.00	0.00	0.00
	Grassland	0.00	0.03	0.00	0.00	0.00
	Forest	0.80	0.76	0.80	0.80	0.80
>30	Arable land	0.00	0.00	0.00	0.00	0.00
	Grassland	0.00	0.01	0.00	0.00	0.00
	Forest	0.01	0.01	0.01	0.01	0.01

On average, erosion occurred on 57% of the Bystrzanka catchment area and deposition occurred on 43% in the period from 1969 to 2010 (Table 3). In all analysed time periods, the greatest proportion of the catchment area was occupied by land that underwent erosion of up to 5 $t \cdot ha^{-1} \cdot year^{-1}$, which constitutes from 65% to 87% (RUSLE) and from 39% to 49% (USPED) of the investigated area.

In the 1970s, areas with very high erosion values (>50 $t \cdot ha^{-1} \cdot year^{-1}$) occupied 0.64 km^2 (RUSLE) and 0.58 km^2 (USPED), which constituted 4.9% and 4.5% of the catchment area respectively (Tables 2, 3, 4). In the subsequent years, a decrease in erosion intensity was observed in the entire catchment area. It was also noticed that the area with slight erosion increased. In the first decade of the 21st century, the catchment area with a high risk of erosion constituted merely 0.17 km^2 (RUSLE) and 0.26 km^2 (USPED).

In both models (RUSLE and USPED), grasslands show an increase of the area with slight erosion (up to 5 $t \cdot ha^{-1}$): from 13.6% in 1969 to 35.6% in 2003 (RUSLE), and from 6.4% to 18.6% (USPED), (Table 4). The values from 1969 constitute approximately 35% (±3%) of the values from 2003 (in both models). Such a difference results from a transformation of arable lands into grasslands. Erosion on arable lands was more diversified in terms of the risk of erosion. Their area decreased in subsequent years in all risk categories. The values from 2003 are lower than from 1969 and in all ranges, constitute approximately 36% (USPED) ±4% (RUSLE), (Table 4). Moreover, a high percentage of the catchment area was affected by erosion greater than 50 $t \cdot ha^{-1}$. In 1969, this value amounted to 4.93% (RUSLE) and 4.05% (USPED) and constituted 10% and 15% of erosion on arable areas, respectively. In total, erosion greater than 5 $t \cdot ha^{-1}$ on grasslands and arable area was 35% in 1969 and 13% in 2003 (RUSLE).

Table 2. Surface area and percentage of erosion (RUSLE) with different land use

RUSLE								
Erosion [$t \cdot ha^{-1}$]	1970		1980		1990		2000	
	Area [km^2]	% of the catchment	Area [km^2]	% of the catchment	Area [km^2]	% of the catchment	Area [km^2]	% of the catchment
0-5	8.47	65.07	10.53	81.05	9.95	76.45	11.34	87.13
5-10	1.13	8.69	0.61	4.67	0.66	5.06	0.42	3.22
10-20	1.31	10.06	0.69	5.32	0.94	7.22	0.49	3.80
20-30	0.71	5.48	0.39	3.00	0.59	4.51	0.29	2.22
30-50	0.75	5.77	0.39	3.02	0.58	4.47	0.30	2.30
>50	0.64	4.92	0.38	2.95	0.30	2.29	0.17	1.32

Table 3. Surface area and percentage of water erosion and deposition class (USPED) with different land use

USPED								
Erosion [t·ha^{-1}]	1970		1980		1990		2000	
	Area [km^2]	% of the catchment	Area [km^2]	% of the catchment	Area [km^2]	% of the catchment	Area [km^2]	% of the catchment
0-5	5.04	38.72	5.86	45.08	5.84	44.87	6.36	48.90
5-10	0.65	5.01	0.35	2.72	0.50	3.85	0.29	2.20
10-20	0.61	4.72	0.36	2.75	0.44	3.40	0.26	1.99
20-30	0.30	2.33	0.19	1.43	0.21	1.58	0.13	1.02
30-50	0.30	2.30	0.20	1.55	0.19	1.46	0.14	1.04
>50	0.58	4.45	0.47	3.59	0.35	2.70	0.26	2.03
Deposition [t·ha^{-1}]	Area [km^2]	% of the catchment	Area [km^2]	% of the catchment	Area [km^2]	% of the catchment	Area [km^2]	% of the catchment
0-5	3.62	27.79	4.25	32.68	4.24	32.60	4.69	36.02
5-10	0.41	3.18	0.25	1.93	0.27	2.06	0.18	1.41
10-20	0.43	3.27	0.27	2.11	0.27	2.09	0.19	1.49
20-30	0.23	1.73	0.15	1.16	0.15	1.14	0.11	0.83
30-50	0.24	1.88	0.17	1.33	0.17	1.29	0.12	0.95
>50	0.60	4.64	0.48	3.66	0.38	2.95	0.28	2.12

The USPED model showed slightly lower erosion values: from 18% (1969) to 8% (2003). The percentage share of the catchment area used as arable land on which soil loss was observed in the USLE model was always higher than in the USPED model. In the case of afforested areas and grasslands with erosion greater than 5 t·ha^{-1}, the correlation was reverse. The USPED-based analyses of deposition in the Bystrzanka catchment indicate that the areas on which deposition of up to 5 t·ha^{-1} occurred increased gradually in subsequent time periods. Such areas constituted 28% of the total catchment area in 1969 and increased to 36% in 2003. The smallest area of the catchment was occupied by deposition of 20-30 t·ha^{-1} (from 0.23 km^2 to 0.11 km^2), (Table 4). The area with deposition above 50 t·ha^{-1} decreased together with changes in land use by approximately 0.11 km^2 per every 10 years. In 2003, the value amounted to 0.28 km^2, which constituted 2.12% of the entire catchment area. Material deposition on meadows in 1969 constituted 6.5% of the total catchment area, but in 2003, the value increased to 15.7%. A reverse trend was observed on arable area. Over time, it was observed that the area with this type of land use, on which deposition occurred, decreased (by 13%), (Table 4). It is observed that the difference between areas with arable land on which deposition occurred and areas on which erosion occurred decreased over time and as a result of changes in land use: from 7.5% (in 1969) to 2.7% (in 2003).

The average size of erosion in the Bystrzanka catchment investigated in given time periods when land use patterns varied, decreased considerably: from 8.27 t·ha^{-1} (1970s) to 2.89 t·ha^{-1} (the first decade of the 21st century according to the RUSLE model). The erosion values obtained as a result of the Bystrzanka catchment modelling were compared with the measurements conducted on experimental plots used for agricultural purposes in Szymbark in 1969-2000. These values do not differ in a significant way. In 1969-1979, average erosion in the summer season equalled 8.2 t·ha^{-1}, but decreased to 4.6 t·ha^{-1} in 1990-2000 (Gil 2009). The average annual size of soil wash on fields where potatoes were grown was 18 times greater than on fields where cereals were cultivated and nearly 340 times greater than on meadows. Considering the proportions of areas occupied by individual crops on Carpathian slopes characteristic of the investigated time periods, Gil (2009) reported that the index of denudation in the catchment area was 0.072 mm per year.

5. DISCUSSION AND CONCLUSION

Examples of the application of the RUSLE and USPED models can be found in the literature (e.g. Pelacani et al., 2008; Demczuk & Gil 2009; Park et al., 2011). Having compared the USPED model to four other erosion models in Bolivia, Saavedra & Mannaerts (2005) obtained the agreement of 23%-53%. In a recent study conducted by Capolongo et al., (2008), the erosion values obtained with the use of the USPED model were considered comparable to direct field measurements in the south of Italy. The erosion and deposition modelling in the Bystrzanka catchment, which was conducted with the use of two models: RUSLE (Revised Universal Soil Loss Equation) and USPED (Unite Stream Power-based Erosion/Deposition) for the period of 1969-2010, allows indicating areas and determining the size of erosion and deposition depending on changes in land use and land cover.

Table 4. Percentage of land use forms in classes of soil erosion in different time intervals depending of the model used

USLE								
Land use	Years	Erosion [t·ha^{-1}]						
		0-5	5-10	10-20	20-30	30-40	40-50	>50
		% of the catchment						
Grassland	1970	13.56	0.04	0.04	0.02	0.01	0.01	0.02
	1980	31.65	0.11	0.14	0.07	0.05	0.03	0.08
	1990	23.42	0.03	0.05	0.04	0.02	0.02	0.02
	2000	35.57	0.06	0.07	0.04	0.03	0.02	0.03
Arable land	1970	12.68	8.45	10.01	5.41	3.42	2.26	4.93
	1980	7.18	4.42	5.15	2.90	1.81	1.11	2.88
	1990	6.51	4.88	7.16	4.42	2.75	1.61	2.25
	2000	4.70	3.02	3.69	2.14	1.37	0.85	1.27
Forest	1970	39.08	0.02	0.02	0.01	0.01	0.00	0.01
	1980	42.40	0.01	0.01	0.00	0.00	0.00	0.00
	1990	46.72	0.02	0.03	0.02	0.02	0.01	0.02
	2000	47.10	0.01	0.01	0.01	0.01	0.00	0.01
Grassland and arable land	1970	26.23	8.49	10.05	5.43	3.43	2.27	4.94
	1980	38.84	4.52	5.29	2.97	1.85	1.14	2.95
	1990	29.93	4.91	7.21	4.46	2.77	1.62	2.27
	2000	40.27	3.08	3.76	2.18	1.40	0.87	1.30

USPED									
Land use	Years	Erosion [t·ha^{-1}]							Deposition [t·ha^{-1}]
		0-5	5-10	10-20	20-30	30-40	40-50	>50	
		% of the catchment							
Grassland	1970	0.23	0.04	0.07	0.10	0.17	0.17	6.42	6.48
	1980	0.69	0.13	0.16	0.23	0.42	0.37	16.14	13.99
	1990	0.32	0.07	0.09	0.12	0.17	0.16	11.89	10.79
	2000	0.47	0.09	0.13	0.18	0.31	0.30	18.63	15.69
Arable land	1970	4.05	0.82	1.28	2.14	4.43	4.65	9.93	19.85
	1980	2.82	0.49	0.73	1.17	2.28	2.25	4.42	11.30
	1990	2.15	0.46	0.75	1.36	3.10	3.54	6.60	11.62
	2000	1.46	0.30	0.47	0.79	1.60	1.78	3.50	7.15
Forest	1970	0.13	0.02	0.03	0.06	0.10	0.08	22.31	16.42
	1980	0.05	0.01	0.01	0.02	0.03	0.04	24.49	17.78
	1990	0.21	0.04	0.05	0.07	0.11	0.09	26.43	19.83
	2000	0.08	0.02	0.02	0.03	0.07	0.06	26.83	20.04
Grassland and arable land	1970	4.29	0.87	1.35	2.24	4.60	4.83	16.35	26.33
	1980	3.51	0.62	0.89	1.39	2.70	2.62	20.56	25.29
	1990	2.47	0.52	0.84	1.48	3.27	3.69	18.49	22.41
	2000	1.93	0.39	0.59	0.97	1.90	2.08	22.14	22.85

The processes that model the surface depend, among other things, on the manner of land use, gradient and shape of slopes as well as sum and intensity of rainfall. Since 1969, a decrease in arable land (by 23% in 2003) and increase in grasslands (by 25% in 2003) have been observed in the Bystrzanka catchment. The erosion processes are observed on approximately 58% of the catchment area (according to the USPED model).

The areas occupied by grasslands show an increase in the area with very low risk of erosion (up to 5 t·ha^{-1}) and a negligible increase in the area with erosion exceeding 5 t·ha^{-1} (according to the RUSLE and USPED models). The area of arable land on which the risk of erosion was recorded amounted to 47% in 1969, but in 2003, it was much lower (by 30% in the RUSLE model and by 13% in the USPED model). In both models, a relatively large area was occupied by areas with erosion that exceeded 50 t·ha^{-1} - up to 5% in 1969 and 1.5% in 2003. The USPED-based simulations of the areas where material deposition occurs in the Bystrzanka catchment indicate a gradual increase in the areas with deposition of up to 5 t·ha^{-1} in subsequent investigated time periods. Moreover, a percentage increase in the areas occupied by grasslands on which deposition occurred and reduction in the area with arable land were also observed. It should be emphasised, however, that in certain cases, despite high kinetic energy of rainfall, which may potentially lead to detachment of soil particles, no erosion is observed in the USPED model.

The average erosion value estimated in the catchment area decreased as land use type changed and as the area occupied by arable land was reduced: from 8.27 t·ha^{-1} in 1969 to 2.89 t·ha^{-1} in 2003. In the Italian Orme catchment, which is similar in size (15 km^2), a reverse trend was observed. The erosion values changed over time from 4.2 t·ha^{-1} in 1954 to 5.3 t·ha^{-1} in 2004. (Pelacani et al., 2008). The increase in erosion suggests a high correlation of its intensity to land use. Moreover, between 1821 and 2004, a reduction in afforestation was observed, which resulted from the expansion of agriculture. In the Czech Massif of the Eastern Sudetes, in the catchment area of the Bystrzyca Dusznicka (197.7 km^2), erosion estimated with the use of the USLE model amounted to 9 t·ha^{-1} (Kowalczyk & Twardy, 2012) and mainly depended on slope steepness and manner of land use.

The size of erosion in the Bystrzanka catchment estimated in the modelling process does not differ in a significant way from the measurements performed on the experimental plots in Szymbark (Gil, 2009). It should be remembered, however, that these values are only approximate since neither of the models tested (neither the RUSLE, nor the USPED) gives a fully reliable image of the erosion risk.

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