

EVALUATION OF SOIL RESILIENCE TO ANTHROPOPRESSURE IN ŁOSIE VILLAGE (LOWER BESKIDS MTS) – PRELIMINARY RESULTS

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Abstract

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This paper presents the preliminary results of research on soil resilience to anthropopressure in Łosie village (Lower Beskids Mts). The considered risks included three features which reflect soil resilience: predicted soil loss caused by water erosion, mechanical and physico-chemical filtration capacities. The average annual rate of soil loss was calculated based on the Revised Universal Soil Loss Equation (RUSLE). Analyses of mechanical and physico-chemical filtration capacities of soils were conducted on the basis of algorithms which took into account the soil texture class and groundwater table class. The results confirmed that the highest predicted soil loss takes place within arable lands, particularly those located on slopes – with up and down tillage. During the period from 1997 to 2009, predicted soil loss decreased by 57% due to the decline in the percentage of arable land in the research area. It was found that the introduction of cross-slope tillage within arable lands could decrease overall predicted soil loss up to 67%. Areas with the lowest mechanical filtration capacities were located on slopes and related to sandy clay soils whereas the areas with the lowest physico-chemical filtration capacities were situated in valley bottoms and are mainly due to the shallow level of the groundwater table. Finally, it was noted that the different types of analyzed risk do not overlap nor even do they correspond with each other, which is conditioned by different features of the environment that were taken into consideration. The obtained results have shown how important sustainable spatial planning evaluation of various types of environmental resilience is.

Key words: soil resilience, water erosion, filtration capacities, RUSLE, Lower Beskids Mts.

Introduction

Sustainable development, in which spatial planning needs to be adjusted to environmental conditions, is a new development strategy of the EU. The spatial planning process should always be preceded by a rigorous assessment of the natural environment. This is especially crucial in a mountain environment, as it is one of the most fragile environments. However, agreement on proper land use is nowadays a challenge for the different stakeholders involved, such as planners, investors and local communities. Accounting for the different types of risk in the evaluation of specific landscape elements is an important step towards sustainable land use. Environmental resilience is a main feature which should be evaluated to distinguish the appropriate spatial development zones.

According to Holling, (1973) "resilience determines the persistence of relationships within a system and is a measure of the ability of the system to absorb changes". In other words it is "the capacity of a system to respond to a perturbation or disturbance by resisting damage and recovering quickly" (Folke et al., 2002). When the "disturbances have sufficient magnitude or duration they may force a system to reach a threshold" and then the deterioration of the system begins (Folke et al., 2002.).

Resilience depends strictly on the type of risk as well as on the element of environment on which the risk stimulus affects. That is why only partial resilience should be considered and only the sum of partial resilience of different environment elements should be identified as environmental resilience. With this approach, resilience of soil, groundwater, surface water, air or flora should be studied individually.

There are many different approaches used to support spatial planning system. One of them is Multicriteria Landscape Assessment and Optimisation (MULBO) created by Meyer and Grabaum (1998). It is a GIS-based method for landscape assessment and optimisation to support the decision-making process in spatial planning. Grabaum et al. (2005) compiled different methods for assessment of particular regulatory functions of environment which include a supply and protective function of groundwater, climatogenic function, regulation of runoff, water and wind erosion of soils as well as soil filtration capacities. These regulatory functions are responsible for maintaining the balance in the environmental system. A sustainable environment is, at the same time, a resilient environment, making these features appropriate for environmental resilience assessment. Likewise, Tracz (2004) presents a set of methods which may be applied to evaluate environmental resilience to degradation. One of them is the evaluation of soil resilience to water erosion. Research on water erosion of soils were, for a long time, the subject of interest for many researchers. Wischmeier and Smith (1978) formulated the Universal Soil Loss Equation (USLE) to predict soil loss caused by water erosion which was later changed by Renard et al. (1997) to the Revised Universal Soil Loss Equation (RUSLE). The equations were used repeatedly for predicted soil loss calculation in different regions of the world (Arghinus, C., Arghinus, V., 2011; Bosco et al., 2009; Igwe et al., 1999; Lastoria et al., 2008; Yue-qing et al., 2009). Also, in the mountain areas of Poland such research was undertaken (Demczuk, 2009; Drzewiecki, 2006; Koreleski, 2008).

Soil is a very important element of the environment which, on one the hand is extremely vulnerable to anthropopressure, and on the other hand provides protection of other parts of the environment. This is especially evident in the filter function of soils. Not only are soils responsible for mechanical filtration and immobilization of pollutants, but also harmful substances are decomposed in them. That is why soil filtration capacities may be used as an indicator of soil resilience. The higher filtration capacities are, the higher the soil resilience is to pollution. On the contrary, predicted soil loss caused by water erosion account for an indicator of the vulnerability of soils itself – the higher the predicted soil loss, the less resilient to environmental erosion.

The aim of the study was to evaluate soil resilience to anthropopressure. Research included three features which reflect soil resilience such as predicted soil loss, mechanical and physico-chemical filtration capacities. Predicted soil loss enable assessment of actual spatial management whereas mechanical and physico-chemical filtration capacities are potential features based on characteristics of the environment.

Material and methods

The evaluation of soil resilience to anthropopressure was conducted for the part of Ropa municipality – Łosie village (Fig. 1). The smallest unit of administrative division was chosen for analysis because the spatial planning process at a local level concerns municipalities and their parts. Characteristic features of the study area are presented in Table 1. Łosie village is located in the Lower Beskids Mts, which is a part of the Outer Western Carpathians. This region is built of the Carpathian flysch and the main tectonic unit there is the Magura Nappe. The elevation in Łosie ranges from 350 to 662 m a.s.l. There are two distinct climatic vertical zones: moderate warm and moderate cool. The mean annual sum of precipitation ranges from 800 to 900 mm and the majority of precipitation occurs in summer (Obrębska-Starkłowa, 1983). The dominant type of soil in Łosie is Eutric Cambisols, in particular: sandy loam, loam, clay loam, sandy clay, silt and silt loam. There are two altitudinal zones in the research area: the foothill vertical zone and lower forest vertical zone covered by the Carpathian beech forest (*Dentario glandulosae-Fagetum*).



Fig. 1. Location of the study area.

T a b l e 1. The characteristic features of study area.

Study area	Łosie village
Physicogeographical subregion	Lower Beskids (Outer Western Carpathians)
Main tectonic unit	Magura nappe
Altitude range	350–662 m a.s.l.
Climatic vertical zones	moderate warm, moderate cool
Annual sum of precipitation	800–900 mm
Dominant type of soil	Eutric Cambisols
Altitudinal zones	foothill vertical zone, lower forest vertical zone
Dominant forest community	Carpathian beech forest (<i>Dentario glandulosae-Fagetum</i>)

T a b l e 2. Land use changes between 1997 and 2009.

Land use	Percentage of the area (%)	
	1997	2009
Arable lands	5.0	2.5
Grasslands	27.9	28.0
Forest	67.1	69.5

The majority of Łosie is occupied by forest, accounting for 69.5% of its total area (Table 2). A significant percentage of the area at lower altitudes is covered by grasslands. Built-up areas are located in the valley bottoms whereas arable lands occupy both valley bottoms and slopes (Figs 2, 3). In the years 1997 and 2009, the area of arable lands decreased from 5 to 2.5% (Table 2). These changes are the consequence of the socio-economic transformation of Poland. As a result of EU membership, afforestation of land supported financially by the EU has become a common decision among land owners. Furthermore, the process of land abandonment is more and more popular since land cultivation and livestock farming have become unprofitable. Despite EU subsidies for agriculture in mountain areas farm production costs often exceed expected profits.

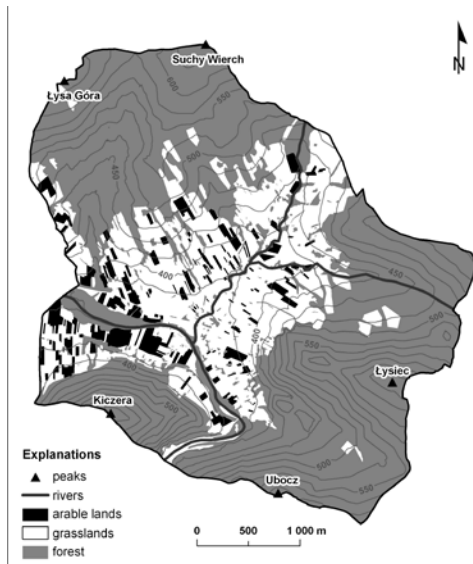


Fig. 2. Land use in 1997.

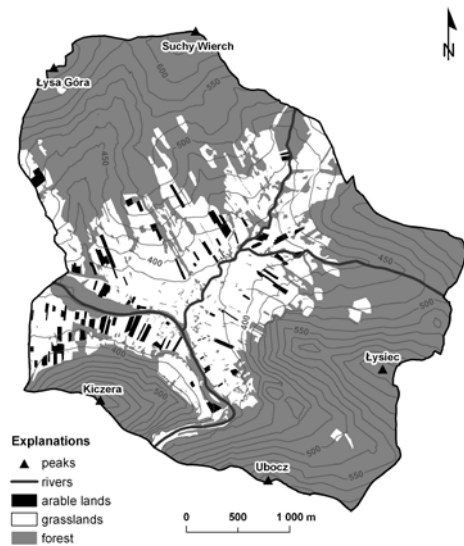


Fig. 3. Land use in 2009.

The research included the calculation of predicted soil loss caused by water erosion as well as an estimation of mechanical and physico-chemical filtration capacities of soils. The study used data consisting of a digital elevation model (TIN), orthophotos, and soil and agrarian maps. Additionally, a land use map was derived from the orthophotos through digitalization. Also, a hydrological paper map required digitalization in order to combine it together with other materials. A map overlapping technique was used for the analyses.

The soil erosion loss analysis was conducted for two different time periods – 1997 and 2009. The sheet and rill erosion rate calculation was based on the Universal Soil Loss Equation (USLE) formulated by Wischmeier and Smith (1978) and then changed by Renard et al. (1997) to the Revised Universal Soil Loss Equation (RUSLE). This equation predicts the long term average annual rate of erosion on a field slope based on rainfall patterns, soil type, topography, crop system and management practices (Stone, Hilborn, 2000). The average annual rate of soil loss caused by erosion was calculated as follows:

$$A = R \times K \times L \times S \times C \times P,$$

where

- A – predicted soil loss [t/(ha*year)],
- R – rainfall and runoff [(MJ*cm)/(ha*h*year)],
- K – soil erodibility [(t*h)/(MJ*cm)],
- L – slope length,
- S – slope steepness,
- C – crop management,
- P – support practices.

Rainfall and runoff factor (R) was a constant value calculated by Demczuk (2009) for the nearby research station in Szymbark and equalled 108.2 (MJ*cm)/(ha*h*year). Soil erodibility factor (K) depending on the soil textural class was attributed to every patch of different soil type (Table 3). Topography factors, i.e. slope length (L) and slope steepness (S), were assigned to each patch of different land use. L-factor values for specific slope length intervals were calculated on the base of the formula proposed by Renard et al. (1997) and S-factor values were derived from the paper by Grabaum et al. (2005) (Tables 4, 5).

Table 3. Values of soil erodibility factor (K) depending on the soil textural class according to Demczuk (2009).

Textural class	Soil erodibility factor (K)
Sandy loam	0.2898
Loam	0.3239
Clay loam	0.3917
Sandy clay	0.4609
Silt	0.4805
Silt loam	0.5101

Table 4. Values of slope length factor (L) calculated on the base of formula of Renard et al. (1997).

Slope length (m)	L-factor		Slope length (m)	L-factor	
	>10°	<10°		>10°	<10°
10	0.6	0.7	400	5.7	3.2
20	0.9	1	450	6.1	3.3
30	1.2	1.1	500	6.5	3.5
40	1.4	1.3	550	6.9	3.6
50	1.6	1.4	600	7.2	3.7
60	1.8	1.5	650	7.6	3.9
70	2	1.6	700	7.9	4
80	2.2	1.7	750	8.3	4.1
90	2.3	1.8	800	8.6	4.2
100	2.5	1.8	850	8.9	4.3
120	2.8	2	900	9.2	4.4
140	3	2.1	950	9.5	4.5
160	3.3	2.2	1000	9.8	4.6
180	3.5	2.3	1050	10.1	4.7
200	3.7	2.4	1100	10.4	4.8
220	4	2.5	1150	10.7	4.9
240	4.2	2.6	1200	11	4.9
260	4.4	2.7	1250	11.3	5
280	4.6	2.8	1300	11.5	5.1
300	4.8	2.8	1350	11.8	5.2
350	5.2	3	1400	12	5.3

Table 5. Values of slope steepness factor (S) according to Grabaum et al. (2005).

Slope steepness (°)	S-factor	Slope steepness (°)	S-factor
3	0.2	16	2.4
4	0.3	17	2.6
5	0.5	18	2.9
6	0.6	19	3.2
7	0.7	20	3.5
8	0.8	21	3.8
9	1	22	4.1
10	1.2	23	4.4
11	1.3	24	4.7
12	1.5	26	5.4
13	1.7	28	6.1
14	2	30	6.8
15	2.2		

The value of crop management factor (C) was attributed according to the land use type (Table 6). However, due to the difficulty in distinguishing particular crops, to all arable lands values for potatoes proposed by Demczuk (2009) were assumed. Finally, support practices factor (P) equaled 1 for the whole study area as no support practice to reduce soil loss caused by water erosion was taken and the tillage was conducted up and down slope. For comparison, the case of cross-slope tillage was tested in which, depending on slope steepness, support practices factor (P) ranged from 0.5 to 0.9.

Table 6. Values of crop management factor (C) depending on the land use according to Demczuk (2009).

Land use	Crop management factor (C)
Arable lands	0.30182
Grasslands	0.00087
Forest	0.00001

Analyses of mechanical and physico-chemical filtration capacities of soils were conducted on the base of algorithms proposed by Altmann et al. (1992). For calculation of both mechanical and physico-chemical filtration capacities, soil texture class and groundwater table class were used. Equations applied to calculate these values are presented below:

$$Fm = S \pm G$$

$$Fpc = S \pm G,$$

where

Fm – level of mechanical filtration capacities,

Fpc – level of physico-chemical filtration capacities,

S – soil texture class,

G – groundwater table class.

The soil textural class is crucial as it estimates filtration capacities and determines the appropriate filtration capacities class. However, various types of soils react differently, depending on the type of pollution. That is why, depending on the type of investigated filtration capacities, classes are different (Table 7). They may be modified by the depth of the groundwater table class (Table 8). Additionally, in case of mechanical filtration capacities, climatic water balance surplus higher than 300 mm would increase their level. However within the whole study area, climatic water balance surplus was lower than 300 mm so the values remained unchanged.

Table 7. Filtration capacities class depending on the soil textural class according to Graubaum et al. (2005).

Textural class	Filtration capacities class	
	Mechanical	Physico-chemical
Sandy loam	4	3
Loam	3	3
Clay loam	3	3
Silt	3	4
Silt loam	4	4
Sandy clay	2	5

Notes: classes of filtration capacities: 2 – very low, 3 – medium, 4 – high, 5 – very high.

Table 8. Modification of filtration capacities class depending on the depth of groundwater table according to Graubaum et al. (2005).

Depth of groundwater table (m)	Filtration capacities class	
	Mechanical	Physico-chemical
< 0.8	-1	-2
0.8–2	0	-1
2–10	0	0
10–30	+1	+1
>30	+2	+2

Results and discussion

As a result, maps of predicted soil loss caused by water erosion for the years 1997 and 2009 were created (Figs 4, 5). The highest predicted soil loss was, in both cases, in arable lands. It was lower in grasslands and the lowest in forest areas (Table 9). Predicted soil loss decreased by 57% during this period of time, which is a result of changes in land use, i.e. a decrease of arable land area. All mean values of the erosion rate also decreased, which is an effect of patches area reduction (Table 9).

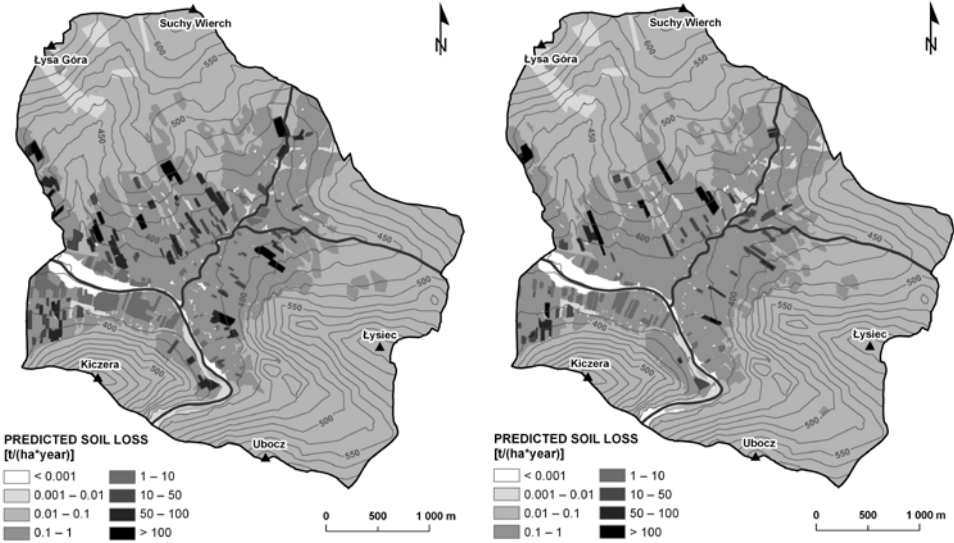


Fig. 4. Predicted soil loss caused by water erosion in 1997 Fig. 5. Predicted soil loss caused by water erosion in 2009.

T a b l e 9. Predicted soil loss caused by water erosion for year 1997 and 2009.

Land use	Erosion		Rate of erosion					
	t/year		Mean		Max.		Min.	
			t/(ha*year)					
	1997	2009	1997	2009	1997	2009	1997	2009
Arable lands	3049	1660	34.10	30.80	164.02	216.75	1.91	1.51
Grasslandss	488	359	0.90	0.61	10.21	5.41	0.01	0.02
Forest	50	40	0.55	0.34	11.38	5.76	0.00	0.00
Total	3587	2060	2.73	1.58	—	—	—	—

Additionally, a trial of landscape optimisation was undertaken. Introduction of cross-slope tillage within arable lands would decrease overall predicted soil loss by 67% (Table 10).

In general, the values of predicted soil loss calculated on the basis of assumptions described above correspond to the results obtained by Demczuk (2009) for Bystrzanka catchment. However, measurements of the research plots indicate that these values are almost three ti-

mes higher than the actual size of the water erosion (Demczuk, 2009). Nevertheless, the calculated values provide some insight into the spatial distribution of soil erosion risk and enable comparisons between specific patches.

T a b l e 10. Predicted soil loss caused by water erosion for year 2009 in case of up&down and cross slope tillage.

Land use	Erosion		Rate of erosion					
	t/year		Mean		Max.		Min.	
			t/(ha*year)					
	up&down	cross slope	up&down	cross slope	up&down	cross slope	up&down	cross slope
Arable lands	1660	1110	30.80	22.88	216.75	195.86	1.51	1.04
Grasslands	359	359	0.61	0.61	5.41	5.41	0.02	0.02
Forest	40	40	0.34	0.34	5.76	5.76	0.00	0.00
Total	2060	1509	1.58	1.12	–	–	–	–

The location of zones characterized by different level of mechanical filtration capacities is presented in Fig. 6. Areas with the lowest mechanical filtration capacities are located on slopes and are marked by sandy clay soils, whereas the highest level of mechanical filtration capacities is in the valley bottoms where the dominant type of soils are sandy loam and silt loam.

Figure 7 shows zones of different levels of physico-chemical filtration capacities. The lowest physico-chemical filtration capacities which simultaneously occur in areas of the lowest resilience are situated in valley bottoms and result mainly from the shallow level of the groundwater table. The highest filtration capacities are characteristic of slopes covered by sandy clay, silt and silt loam.

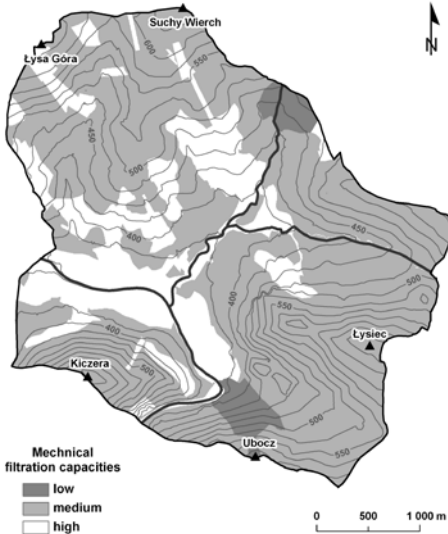


Fig. 6. Mechanical filtration capacities of soils.

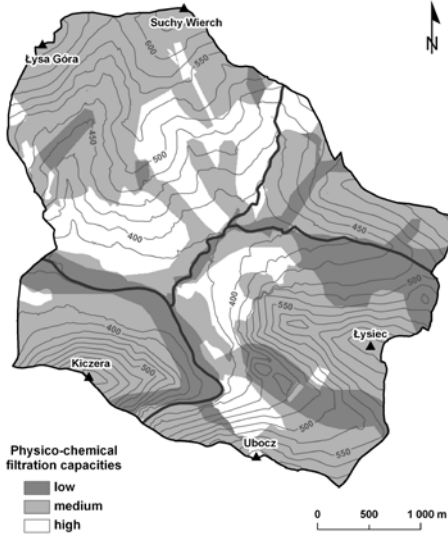


Fig. 7. Physico-chemical filtration capacities of soils.

Additionally, different kinds of predicted risks – high rate of erosion, low mechanical and physico-chemical filtration capacities – are combined on one map (Fig. 8). It is worth emphasizing that different types of risk presented in Fig. 8 do not overlap nor even do they correspond with each other, which should be an important detail for spatial planners.

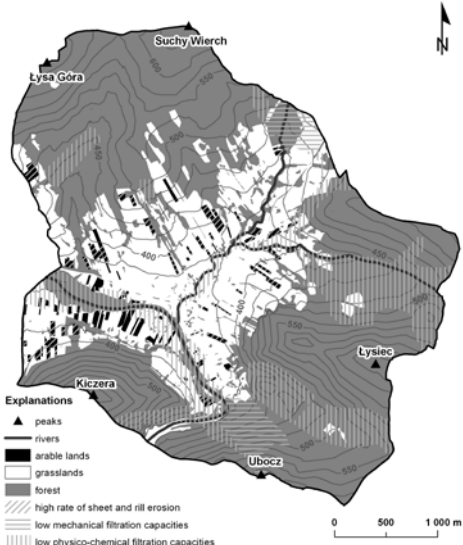


Fig. 8. Different kinds of predicted risks.

Conclusion

To sum up, the presented results provide an overview of the soil resilience distribution in Łosie village. The main advantage of the presented study is the combination of different features of soil resilience. It is crucial that the zones of particular resilience types are distributed independently of each other and that what is conditioned by different features of the environment are taken into consideration in the analyses. It is especially crucial in the spatial planning process to know precisely in which way a particular pressure threatens the environment and which environmental features are unaffected. Depending on the target land use, more area could require exclusions from specific types of use, or, on the contrary, a certain activity may endanger only one type of environmental feature and only this one should be taken into consideration. According to the spatial planning goal, other kinds of soil features e.g. immobilization and transformation capacities as well as different types of pressure may be considered.

However, this small piece of research in the field of soils has shown how complex an issue environmental resilience is. Even different types of soil resilience were found to have a distinct density. In other environmental elements this spatial distribution of resilience would be much more diverse, which is why it is important to include the various types of resilience during environmental resilience evaluation.

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