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POTENTIAL EROSION OF THE AREAS DEFORESTED FOR SKI SLOPES – AN EXAMPLE OF MOUNT JAWORZYNA KRYNICKA

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Abstract

Erosion is a natural phenomenon which constantly changes the shape of the Earth's surface, yet it is regarded as a very serious harmful factor by people in view of their economic and investments activities. Ski slopes are a special example of areas with a serious erosion hazard due to a permanent deforestation, considerable longitudinal slopes, engineering works, levelling ski slopes, but also because of abundant surface runoff. The aim of the research was to compare the extent of potential soil erosion in deforested areas intended for ski slopes, with various anti-erosion measures implemented, as well as to discuss the possibility of RUSLE erosion model application under these conditions.

The researched objects were ski runs on the eastern slopes of Mount Jaworzyna Krynicka (The Beskid Sądecki Mts.). Potential erosion was computed in the areas of seven ski slope segments in four variants of the area cover and applied anti-erosion measures. Some computational data (the ski slope area, average slope gradients, soil granulometric composition) were obtained from the Forest Digital Map and Digital Terrain Model, whereas numerical indicators used for the model were established on the basis of the subject literature.

Under presented conditions, potential erosion losses were greatly diversified. The biggest losses, expressed as erosion losses factor *A*, have been indicated for variant I (naked soil, without anti-erosion measures) and varied from ca. 18 to ca. 36 $Mg \cdot ha^{-1} \cdot year^{-1}$. Sodding ski slopes diminished potential erosion to 4.5% of the value obtained for the comparative variant (variant I), while shortening of the surface runoff length without sodding may reduce potential erosion losses to ca. 20÷25%. Combination of both measures may significantly reduce the erosion in these areas (to ca. 0.04%). The obtained results are analogous to other authors' findings.

Keywords: potential erosion, RUSLE, deforestation, ski slopes, GIS

INTRODUCTION

Erosion is a natural phenomenon which constantly changes the shape of the Earth's surface, but it is perceived by the man as a most serious harmful factor for his economic and investment activities. The factors intensifying erosion processes are, among others, water (also ice) movement on the ground surface, gravitation, a change of water permeability of the ground top layers or removal of the vegetal cover. Therefore, erosion may be reduced through, among others, diminishing the land slope, ground covering with vegetation and limiting the surface runoff (Józefaciuk and Józefaciuk 1999; Koreleski 2008).

Losses caused by a "single erosion incident" are distributed over areas of different sizes, but the part of an area wherethe soil loss occurred may be identified, as well as the one where the soil was later deposited. Sorting of the soil usually happens during its transport. Losses in the areas managed by the man involve, among others, disturbances in the land plane geometry and staticsof objects, which may have implications for the safety of the area users and cause a temporary or permanent exclusion of the damaged areas from use. Returning their proper functionality usually requires considerable financial outlays.

Ski slopes are particular cases of areas facing a considerable erosion hazards due to: permanent deforestation, considerably big longitudinal land slopes, engineering works, levelling the ski slopes (violation of hitherto undisturbed slope), but also because of abundant surface runoff (particularly during spring snowmelt and torrential rain). Therefore, in their own interest the ski slope owners should care about the minimization of losses caused by erosion on these objects. It may be achieved by permanent sodding of the ground area as soon as possible and shortening the way of surface runoff through digging transverse draining ditches for draining collected water to the natural slope beside the ski run. At the same time attention should be paid to a threat of land slides or linear erosion in the places of the discharge of water drained in this way, which often are the other owners' properties.

The aim of the research was to compare the extent of potential soil erosion in deforested areas intended for ski slopes, with various anti-erosion measures implemented, as well as to discuss the possibility of RUSLE erosion model application under these conditions.

MATERIALS AND METHODS

The studied areas included former grounds of the Forest Experimental Unit (LZD) and Piwniczna Forest District (eastern slopes of Mount Jaworzyna Krynicka, the Beskid Sądecki Mts.), which ca. 20 years ago were deforested for the purpose of arranging there ski slopes of various difficulty levels. After deforestation, a construction project was realized there, which adjusted the land slopes to specific requirements. The map (Fig. 1) shows the course of individual ski slopes, whose boundaries were determined for the needs of the present paper on the basis of the location of lower and upper stations of ski lifts. The numbering of the ski slopes is compliant with the numbering used by the owners of the object.

Geometrical data and descriptions of the surrounding tree stands were obtained from the Forestry Experimental Unit of the University of Agriculture in Krakow (LZD) and Forest Data Bank (www.lzdkrynica.ur.krakow.pl; www.bdl.lasy.gov.pl). The topography of the terrain and data concerning the slope gradients were acquired from the Digital Terrain Model (DTM).

The data characterizing selected areas (Table1), such as: surface area, the length of slopes and their gradients, vegetal cover and the particle size of soil deposits, were acquired from the attribute table of appropriate layers and own analyses of the Forest Digital Map (resolution: units) and DTM (pixel 1m).

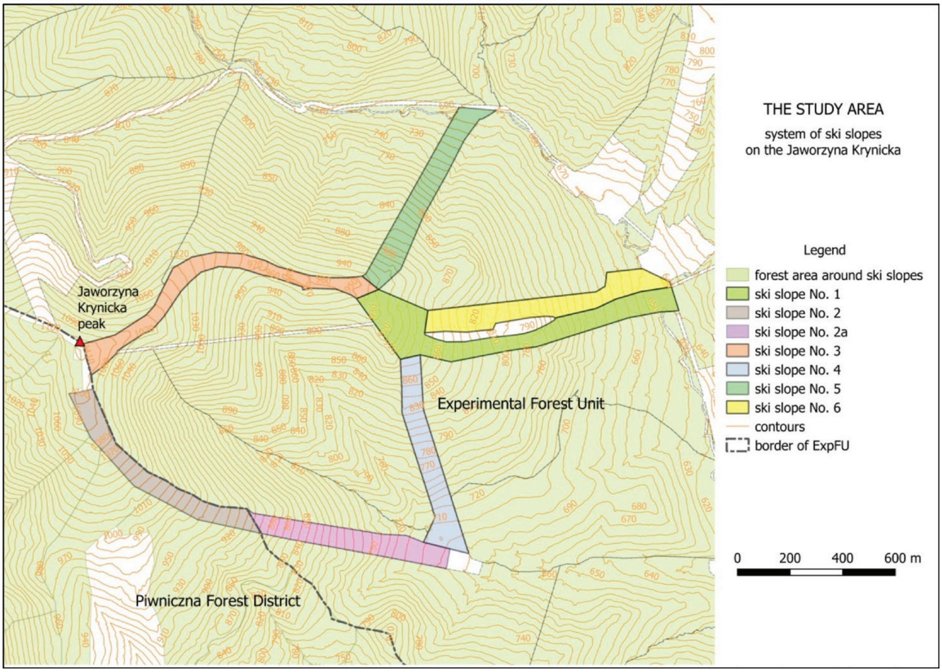
Table 1 . Characteristics of ski slope areas

ski slope number	area	ski slope length	average gradient of ski slope	average fraction content (PTG classification 2008)			average distance between draining ditches
				sand	silt	Clay	
	[ha]	[m]	[°]		[%]		[m]
1	11.20	1271.3	15.3	25.3	53.6	21.1	50
2	6.39	871.7	14.1	34.4	56.4	9.2	50
2a	5.94	749.9	15.9	33.0	54.1	12.9	50
3	7.55	1267.4	13.6	33.5	56.8	9.7	50
4	6.45	744.0	14.8	28.8	52.3	18.9	50
5	6.83	773.9	19.5	25.1	53.7	21.2	50
6	7.41	908.4	16.2	24.9	54.4	20.7	50

Precipitation data for the multiannual period for Krynica-Zdrój were obtained from the paper by Woźniak (2013) (Table 2). Because of the form of the available data, stability of rainfall spatial distribution was assumed.

Table 2. Average precipitation for the multiannual period 1881-2010 for Krynica-Zdrój (Woźniak 2013).

average monthly precipitation total [mm]												average annual precipitation total [mm]
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
51.5	45.9	49.5	58.1	90.4	113.8	116.5	100.0	73.5	60.1	50.7	52.7	862.7



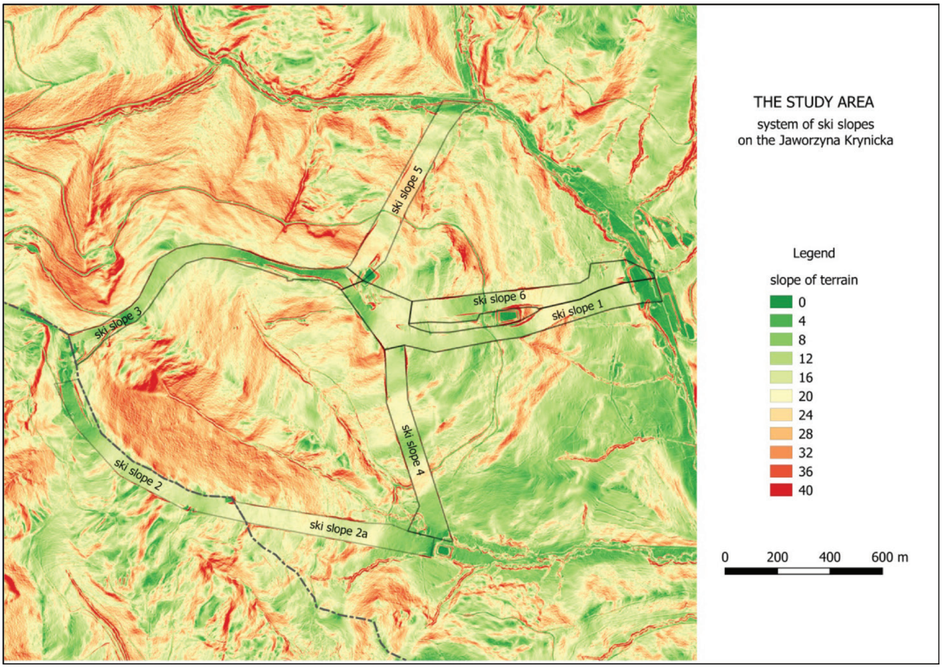
Source: own elaboration on the basis of Forest Digital Map LZD and DTM

Figure 1. Map of the studied area with objects selected for analyses

Potential erosion was computed in the areas of seven segments of ski slopes in four combination variants, which were defined by different area cover and technical anti-erosion measures applied. The owner of the ski slope area applied organic fertilization and sowed grass on the slopes in order to reduce the erosion losses, and also dug transverse draining ditches, which shortened the length of the surface runoff (Fig. 3). Following variants were taken into consideration:

- Variant I: soil without cover (naked), without technical anti-erosion measures,
- Variant II: sodded soil, without technical anti-erosion measures,
- Variant III: soil without cover (naked), with transverse draining ditches,
- Variant IV: sodded soil, with transverse draining ditches.

It would be interesting to determine potential erosion for the areas of these ski slopes prior to their deforestation and earth works levelling their longitudinal profile. Since the Authors did not have the DTM from the period before these works were accomplished, they present, for comparison, appropriate computations for the current geometrical and altitudinal status of the ski slopes areas at natural forest cover (variant V).



Source: own elaboration on the basis of Forest Digital Map LZD and DTM

Figure 2. Map of land slopes of the area covered by the investigations

Fig. 3 shows exposure of the ground profile at ski slope No. 3 transformed by engineering works, which involve the levelling of the longitudinal profile of the ski run surface, organic layer distributed on the ski slope surface for faster sodding and the view of a ditchdraining the ski slope surface.

Figure 3. An example of the scope of engineering works and anti-erosion measures performed in the ski slopes areas. Photo by J.Gołąb

Potential erosion on selected surfaces was computed by means of a popular RUSLE (Revised Universal Soil Loss Equation) model (Renards *et al*. 1997), where the ski slopes were treated as permanent pastures or bare fallow. The model is used for calculation of potential erosion in agricultural areas.

According to the RUSLE model, the erosion losses factor is given by the following formula:

$$A = R \cdot K \cdot LS \cdot CP \tag{1}$$

where: A – the erosion losses factor[$Mg \cdot ha^{-1} \cdot year^{-1}$],
R – rainfall erosivity factor [$MJ \cdot cm \cdot ha^{-1} \cdot h^{-1} \cdot year^{-1}$],
K – susceptibility to soil erosion [$Mg \cdot ha^{-1} \cdot MJ \cdot ha^{-1} \cdot mm \cdot h^{-1}$],
LS – area topography factor [-],
CP – ratio of area coverage and applied anti-erosion measures [-].

Rainfall erosivity index R is given by the following formula (Licznar 2004, Wężyk *et al.* 2012):

$$F = \sum_{i=1}^{12} \frac{p_i^2}{P} = 80.7254 \tag{2}$$

where: p_i – average month (multi-annual) precipitation total (Table 2),
P – average yearly (multi-annual) precipitation total (Table 2).

$$R = 0.2265 \cdot F^{1.2876} = 64.6449 \tag{3}$$

Computed R = 64.6449 (equal value of rainfall erosivity factor) was assumed for the whole studied area.

Soil susceptibility to water erosion index K is given by the following formula (Drzewiecki *et al.* 2008):

$$K = 0.0034 + 0.0405 \cdot exp\left[-0.5\left(\frac{logD_g + 1.659}{0.7101}\right)^2\right] \tag{4}$$

$$D_g = exp\left(0.01 \cdot \sum f_i \cdot ln \frac{d_i + d_{i-1}}{2}\right) \tag{5}$$

where: D_g – index of soil granulometric composition computed on the basis of sand, silt and clay fractions contents,

d_i – upper diameter of soil fraction,

d_{i-1} – lower diameter of soil fraction,

f_i – percentage of soil fraction (Table 1).

Slope length index *L* is given by the formula which includes the fact that the ski slopes are not terraced (Wischmeier, Smith 1978):

$$L = \left(\frac{\lambda}{22.13}\right)^m \tag{6}$$

where: λ – slope length [m] (Table 1),

m – the exponent for slope inclination: for $i<3^\circ$ $m=0.3$, for $3^\circ<i<5^\circ$ $m=0.4$, for $i>5^\circ$ $m=0.5$).

Slope gradient index S is given by the following formula (Wischmeier, Smith 1978):

$$S = 65.41 \sin^2 i + 4.56 \sin i + 0.065 \tag{7}$$

where: *i* – slope gradient [°] (Table 1).

Average gradients were assumed, the same for the whole ski slope area.

The following values of C (Vegetal cover index) ratio were assumed (Rosse 1997, Drzewiecki, Mularz 2005, Bazoffi 2013):

- for naked soil after engineering works: 1.0,
- for sodded ground: 0.045,
- for afforested ground: 0.001.

Value of factor *C* for the sodded ground was increased, in relation to the value used in the literature of the subject, due to the quality state of the existent area sodding.

Anti-erosion measurements index is given by the formula (Rosse 1997, Drzewiecki, Mularz 2005, Bazoffi 2013):

$$P = D \cdot Md \tag{8}$$

where: *D* – direction of cultivation; *D* = 1.0 was assumed,

M_d – cultivation method; for naked and sodded ground $M_d = 0.25$; for afforested ground:

$M_d = 0.01$.

Computations and analyses were conducted using Microsoft Excel and QGIS 2.18.2 Las Palmas Programmes.

RESULTS

Table 3 presents results of computations. Variant I was treated as comparative state.

Table 3. List of results of computations for the indices used in the model.

No. of ski slope	R	K	LS	CP	A_n	A_n / A_1	potential erosion losses	
						[%]	[Mg·year^{-1}]	[m^3·year^{-1}]*
variant I								
1	64.6449	0.043	44.182	0.2500	30.4406	-	340.840	162.3
2		0.035	31.743		18.0757	-	115.563	55.0
2a		0.037	36.148		21.8819	-	129.904	61.9
3		0.036	36.112		20.9483	-	158.072	75.3
4		0.041	31.879		21.2022	-	137.742	65.6
5		0.043	52.440		36.1836	-	247.029	117.6
6		0.043	41.054		28.2922	-	209.504	99.8
variant II								
1	64.6449	0.043	44.182	0.0113	1.3698	4.5%	15.338	7.3
2		0.035	31.743		0.8134	4.5%	5.200	2.5
2a		0.037	36.148		0.9847	4.5%	5.846	2.8
3		0.036	36.112		0.9427	4.5%	7.113	3.4
4		0.041	31.879		0.9541	4.5%	6.198	3.0
5		0.043	52.440		1.6283	4.5%	11.116	5.3
6		0.043	41.054		1.2731	4.5%	9.428	4.5
variant III								
1	64.6449	0.043	8.762	0.2500	6.0369	19.8%	67.595	32.2
2		0.035	7.603		4.3292	24.0%	27.678	13.2
2a		0.037	9.334		5.6504	25.8%	33.544	16.0
3		0.036	7.173		4.1608	19.9%	31.397	15.0
4		0.041	8.264		5.4964	25.9%	35.708	17.0
5		0.043	13.329		9.1972	25.4%	62.790	29.9
6		0.043	9.632		6.6376	23.5%	49.152	23.4

No. of ski slope	R	K	LS	CP	A_n	A_n / A_1	potential erosion losses	
						[%]	[Mg·year^{-1}]	[m^3·year^{-1}]*
variant IV								
1	64.6449	0.043	8.762	0.0113	0.2717	0.9%	3.042	1.4
2		0.035	7.603		0.1948	1.1%	1.245	0.6
2a		0.037	9.334		0.2543	1.2%	1.509	0.7
3		0.036	7.173		0.1872	0.9%	1.413	0.7
4		0.041	8.264		0.2473	1.2%	1.607	0.8
5		0.043	13.329		0.4139	1.1%	2.826	1.3
6		0.043	9.632		0.2987	1.1%	2.212	1.1
variant V								
1	64.6449	0.043	44.182	0.0001	0.0122	0.04%	0.136	0.06
2		0.035	31.743		0.0072	0.04%	0.046	0.02
2a		0.037	36.148		0.0088	0.04%	0.052	0.02
3		0.036	36.112		0.0084	0.04%	0.063	0.03
4		0.041	31.879		0.0085	0.04%	0.055	0.03
5		0.043	52.440		0.0145	0.04%	0.099	0.05
6		0.043	41.054		0.0113	0.04%	0.084	0.04

* average soil bulk density at average moisture content was assumed: $\rho = 2.1 g\cdot cm^{-3}$

SUMMARY AND CONLUSIONS

Results obtained from erosion models are based on the values describing the studied area and numerical factors obtained from the field experiments. Final values concerning the estimated potential erosion depend on the applied model, the way of introducing the parameters and their values. Under presented conditions of computation variants, using RUSLE model and parameter values averaged for the whole ski slopes area, potential erosion losses are greatly diversified. According to expectations, the highest factors of soils losses *A* were demonstrated for variant I (naked soil, without any technical anti-erosion measures) reaching the values ranging from ca.18 to ca. 36 Mg·ha^{-1}·year^{-1} (Table 3). This variant was used as a comparison base and the subsequent computations were referenced to these values. The authors found that ski slope sodding would reduce potential erosion to 4.5% of the value of the comparative variant (Table 3). The shortening of the surface runoff, without the area sodding, may result in limiting potential erosion losses to ca. 20÷25% (Table 3). Combining both anti-erosion measures may reduce erosion to ca. 1.0% of the comparative state (Table 3), whereas permanent cover of the natural forest would actually eliminate erosion in these areas (reduction to ca. 0.04%).

Both the estimated results of soil losses stated by Bennet (1955) and quoted in "Erosion vademecum" of the Erosion Research Centre in Puławy indicate the same. According to the above-mentioned publications, estimations for the slope with thrice lower gradients than the gradients noted on ski slopes, on bare fallow show that a 18 cm thick soil layer would be washed out during 18 years. At permanent area soddingsimilar soil losses would appear after 82 150 years, whereas in the areas covered by primeval forest only after 575 000 years. These periods expressed as per cent in relation to the time for the ground without cover, would yield 0.02% and 0.003% for sodding and forest, respectively.

Regarding the obtained results in view of Bennet's estimations, a considerable convergence of the erosion dependence on the ground cover conditions may be seen, although the numbers are obviously different. However, one should take into consideration a big difference of the slope gradient and the fact that a change of erosion with increase in the slope gradient is not of linear character. Therefore, it may be supposed that application of RUSLE model, intended for typically agricultural areas and for shorter slopes than in the presented area, has been justified under the described conditions and the results are worth noting.

The Authors think that:

- obtained results clearly indicate a high effectiveness of the applied anti-erosion measures – permanent sodding is crucial for the objects of this kind;
- applied RUSLE erosion model may be used in this case due to the character of the ski slope coverage (naked ground, permanent pasture); the easiness of its application and completing the necessary input data have been emphasized;
- removing all natural soil cover on steep slopes and heavy earth works conducted to obtain the right ski slope profiles enhanced potential erosion hazard on these objects many times, therefore application of appropriate anti-erosion measures is necessary;
- proper analyses conducted in GIS environment are most helpful for the data processing. These analyses were used in the presented paper only to a small extent: to determine the length and area of the objects, their average gradients, but also for visualization.

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REFERENCES

Bazzoffi P. (2013). *USLE calculator*. Excel sheet to calculate the erosion potential.

Bennett H.H. (1955*). Elements of soil conservation*. 2ed. McGrawHill, New York, USA, p.358.

Drzewiecki W., Mularz S. (2005). *Model USPED jako narzędzie prognozowania efektów erozji i depozycji materiału glebowego*. Roczniki Geomatyki, III(2): 45-55.

Drzewiecki W., Mularz S., Twardy S., Kopacz M. (2008). *Próba kalibracji modelu RUSLE/SDR dla oceny ładunku zawiesiny wprowadzanego do Zbiornika Dobczyckiego ze zlewni bezpośredniej*. Archiwum Fotogrametrii, Kartografii i Teledetekcji, 18: 83-98.

Józefaciuk A., Józefaciuk Cz., (1999). *Ochrona gruntów przed erozją – poradnik*. MOŚrZNiL – NFOŚriGW – IUNG Puławy: 1-109.

Koreleski K., (2008).*Wpływ czynników terenowych na natężenie erozji wodnej na przykładzie wsi górskiej*. Infrastruktura i Ekologia Terenów Wiejskich, 3: 5-12.

Licznar P. (2004). P*rognozowanie erozyjności deszczy w Polsce na podstawie miesięcznych sum opadów*. Archiwum Ochrony Środowiska, 30(4): 29 – 39.

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

Renard K. G., Foster G. R., Weesies G. A., McCool D. K., Yoder D. C. (1997). *Predicting Soil Erosion by Water: A Guide to Conservation Planning With the Revised Universal Soil Loss Equation (RUSLE*). U.S. Department of Agriculture, Agriculture Handbook No. 703.

Roose E.J. (1977). Application of the Universal Soil Loss Equation of Wischmeier and Smith in West Africa. In: Greenland, D.J., Lal R. (eds.). Conservation and Soil Management in the Humid Tropics. Wiley, Chichester, England. 177-187.

Wężyk P., Drzewiecki W., Wójtowicz-Nowakowska A., Pierzchalski M., Mlost J., Szafrańska B. (2012). *Mapa zagrożenia erozyjnego gruntów rolnych w Małopolsce na podstawie klasyfikacji OBIA obrazów teledetekcyjnych oraz analiz przestrzennych GIS*. ArchiwumFotogrametrii, KartografiiiTeledetekcji Vol. 24: 403-420.

Wischmeier W. H., Smith D.D. (1978). *Predicting rainfall erosion losses: A guide to conservation planning*. U.S. Dep. Agric., Agric. Handb. No. 537.

Woźniak A. (2013). *Opady w 2010 roku w Karpatach Polskich na tle wielolecia 1881–2010*. Prace Geograficzne, 133: 35 – 48. doi: 10.4467/20833113PG.13.009.1099.

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