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Original Research

Digital Map of Water Erosion Risk in Poland: A Qualitative, Vector-Based Approach

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Abstract

Poland remains one of the few countries with nationwide assessment of erosion risk in detailed scales. An existing map of potential water erosion risk was produced in 1980 according to the qualitative method of potential water erosion risk (PWER) indicator, developed by Anna and Czeslaw Jozefaciuk. The potential erosion risk indicator means an erosion thread for the soil without any plant cover and based on only relatively static factors of slope, soil kind (texture) and average annual rainfall, distinguishing five grades of erosion intensity. The indicator provides no information for real and actual state of erosion risk, which depends mostly on the kind of land use. Therefore, an effort has been made to produce a map of actual water erosion risk for Poland, based on the Józefaciuks' methodology for the qualitative indicator of actual water erosion risk (AWER), which includes a land use factor as well as a factor for erosion prevention techniques.

The work includes the production of an actual water erosion map based on the digitized map of potential water erosion at a scale of 1:300,000 and CORINE Land Cover 2000 as a source for land use information. The results show relatively high actual erosion risk in highest intensities: 1.7% of Poland under very strong erosion, 1.0% under strong erosion and 4.4% under average erosion. Compared to potential water erosion, where the same grades cover 17.6% of the country's area, the erosion risk at high grades decreased by 10.5%. According to the land use structure derived from CLC2000, around 2,300,000 hectares show the risk of water erosion in high erosion intensity grades and require erosion control measures.

Keywords: water erosion, actual erosion risk, erosion risk indicator, nationwide assessment

Introduction

The share of land surface potentially threaded with water erosion in Poland amounts to 30%, while the erosion intensities in grades from average to very strong have the share of ca. 17% of the country's area [1]. The average annual soil loss due to water surface erosion in Poland amounts to 76Mg·km^{-2}, according to Jozefaciuk [2], while the extremes oscillate between 2.7 to 280 Mgkm^{-2}, according to Maruszczak [3].

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Poland has a nationwide map of potential water erosion indicator (PWER) in scale of 1:300,000, made in 1980 by Anna and Czeslaw Józefaciuk [2, 4]. The map was produced from 1:25,000 slope maps derived from topographical maps and 1:300,000 soil maps, and it has been positively validated in detailed studies at a scale of 1:5000. The potential water erosion risk (PWER) indicator distinguishes five grades of water erosion intensity, although the map developed for the indicator was generalized to three grades. The potential water erosion risk presents a static type of indicator, utilizing relatively constant factors of soil texture, slope and average annual rainfall. In constraint the indicator of actual water erosion risk (AWER), developed also by the Józefaciuks [4], contains the dynamic factor of land use and agrotechnique, which strongly influences the intensity of surface water erosion.

The lack of national spatial land use information for Poland limited the application of actual water erosion risk indicators to detailed local, small-area studies [5-7], based mostly on satellite scenes, aerial orthophoto maps and high resolution DEMs. The results of these detailed studies, compared to the results of physical modeling, revealed good representation of the Józefaciuks' qualitative indicators regarding the physics of water erosion processes [6].

Thanks to the publication of the CORINE Land Cover [8, 9], frequently updated land use information allows for the assessment of actual water erosion risk. The results present a basis for decision making within country-wide as well as regional strategies and projects regarding spatial planning, soil protection and rural development.

Method

The analysis was performed on the base of the Józefaciuk [4] method, which introduces five grades of erosion intensity, distinguished by an overlay operation of spatial layers representing: soil type (texture), slope, average annual rainfall and land use type. A detailed scheme of the method is shown in Table 1.

Table 1. Decision rule for the estimation of actual water erosion indicator [4].

Soil groups according to their susceptibility to water erosion	Slope inclina-ton	Small-area fields						Orchards		Perma-nent grass-lands
		Conventional tillage with plow direction:			Conservational tillage with plow direction:					
		Slope-along	Perpen-dicluar to slope	terraces	Slope-along	Perpen-dicluar to slope	terraces	On ter-races and sod	In sod belts perpen-dicular to slope	
Very high suscepti-bility Loess and less-like, silts	do 3°	1	0	0	0	0	0	0	0	0
	3– 6°	2	0	0	1	0	0	0	0	0
	6–10°	3	1	1	2	0	0	0	1	0
	10–15°	4	2	2	3	1	1	1	2	1
	>15°	5	3	3	4	2	2	2	3	2
High susceptibility Loose sands, rendzi-nas	do 3°	1	0	0	0	0	0	0	0	0
	3– 6°	1.2	0	0	0.1	0	0	0	0	0
	6–10°	2.3	1	0.1	1.2	0	0	0	0.1	0
	10–15°	3.4	1.2	1.2	2.3	0.1	0.1	0.1	1.2	0.1
	>15°	5	3	3	4	2	2	2	2	2
Average susceptibility Weak sands, loamy sands, gravels, old rendzinas	do 3°	0.1	0	0	0	0	0	0	0	0
	3– 6°	1.2	0	0	0.1	0	0	0	0	0
	6–10°	2.3	0.1	0.1	1.2	0	0	0	0.1	0
	10–15°	3.4	1.2	1.2	2.3	0.1	0.1	0.1	1.2	0.1
	>15°	4.5	2.3	2.3	3.4	1.2	1.2	1.2	2.3	1.2
Low susceptibility Light loams, aver-age loams, calcarous loams.	do 3°	0	0	0	0	0	0	0	0	0
	3– 6°	0	0	0	0	0	0	0	0	0
	6–10°	0	0	1	0	0	0	0	0	0
	10–15°	3	1	1	2	0	0	0	0	0
	>15°	4.5	2.3	2.3	3.4	1.2	1.2	1.2	2.3	1.2
Very low susceptibility Heavy loams, clays, rocky soils, heavy soils with non-calca-rous skeleton, peats.	do 3°	0	0	0	0	0	0	0	0	0
	3– 6°	0.1	0	0	0	0	0	0	0	0
	6–10°	1.2	0	0	0.1	0	0	0	0	0
	10–15°	2.3	0.1	0.1	1.2	0	0	0	0.1	0
	>15°	3.4	1.2	1.2	2.3	0.1	0.1	0.1	1.2	0.1

Explanations of Tables 1 and 2:
In cases of two erosion grades occurring simultaneously in one record, the lower value is taken for areas with average annual rainfall below 600mm, the highest for remaining areas. In cases of some cells in Table 2, the third erosion risk grade is applied to areas with average annual precipitation exceeding 800mm.
The grades of the intensity of surface water erosion:
0. no erosion: does not occur on given area; 1. weak erosion: causes only small surface soil losses; 2. moderate erosion: causes visible wash-off of humus horizon and worsening of soil properties. The full regeneration of soil is not always possible through conventional tillage; 3. average erosion: may lead to total reduction of humus horizon and development of soils with typologically un-formed profiles. Terrain dismemberment is starting. Considerable debris flow into surface waters; 4. strong erosion: can cause total destruction of soil profile, including the parent rock. This results in large fragmentation of terrain's relief and deformation of hydrology; 5. very strong erosion: effects similar to grade 4, but more intensive, driving into permanent degradation of ecosystems.

Table 2. Decision rule for the estimation of potential water erosion indicator [4]

Soil groups according to their susceptibility to water erosion	Slope inclinations [%]				
	0 – 6	6 – 10	10– 18	18 – 27	>27
	Degree of erosion thread				
Very high susceptibility Loess and less-like, silts	1	2	3	4	5
High susceptibility Loose sands, rendzinas	1	1; 2	2; 3	3; 4	5
Average susceptibility Weak sands, loamy sands, gravels, old rendzinas	1	1; 2	2; 3	3; 4	4; 5
Low susceptibility Light loams, average loams, calcarous loams.	0	1	2	3	4; 5
Very low susceptibility Heavy loams, clays, rocky soils, heavy soils with non-calcarous skeleton, peats.	0	1	1; 2	2; 3	3; 4; 5

The initial analysis used best available spatial data sets: SRTM 90m DEM, 1:500,000 soil map and CORINE [10, 11] revealed extremely low results compared to a potential soil erosion risk (PWER) map made by the Józefaciuks. We decided to use PWER map as a base for estimating actual water erosion risk (AWER) as a data source carrying quality information on terrain slope (generalized from 1:25,000 topographical maps) as well as on soil cover delineated from the 1:300,000 soil map.

The potential erosion risk indicator (PWER) [Table 2] can be interpreted as an erosion intensity on slope-along plowed land in black fallow, the decision rule for an actual water erosion indicator can be transformed to a set of reduction factors, diminishing potential erosion intensity [4]. The values of the reduction factor, assumed for particular Corine Land Cover land use classes are given in Table 3. As CLC data carries limited quantity of information we have simplified the original decision rule, assuming all land use types mentioned in the method are maintained with no erosion control measures.

Since the original map of potential water erosion presents a generalization of source 1:25,000 maps (reclassified from 5- to 3-grade erosion risk) we had to reverse the process of generalization to achieve 5-grade erosion intensity as in the original method. To adopt the three-class map of potential water erosion to original decision rule for AWER indicator, we have assumed two approaches, considering the highest and the lowest erosion risk grade within a 3-grade classification (Table 4). The results are considered maximal and minimal actual water erosion risks.

The source data have been transformed to Polish PUW 1992 projection. CLC database has been reclassified to adopt it to decision rule, as described in Table 3. The actual erosion map has then been produced by overlaying the vector dataset of potential water erosion map with reclassified CLC2000 vector data set (Table 4) and making database operations subtracting reduction factors from potential erosion intensities. The zero and negative AWER values were classified in a "no erosion" category. The results are considered as maximal and minimal actual water erosion risks.

Results

The analysis results show the area undergoing most devastative erosion grades (between 3 and 5) covers about 7.1% of the country's area. These grades are mostly located on uplands, mountains and lake districts i.e. on the terrains with relief. The total area of land under water erosion risk covers between 16.4% and 18.2% of Poland. Detailed results are shown in Table 5.

Comparing the potential (Fig. 1, Table 4) and the actual (Figs. 2 and 3, Table 5) water erosion risk in Poland, a significant reduction of areas undergoing the most destructible erosion grades (i.e. grades form 3 to 5) is clearly visible.

Disscusion

The most important factor – the share of the areas under average-to-very-strong erosion grades [2, 4] equaled 16.5% in potential erosion map and to 7.1% in both actual erosion maps, although the minimal actual erosion map does not contain values for fifth grade of water erosion. The lack of the highest erosion grade in minimal actual erosion map comes from the initial assumption of the lowest grade of 5-classes within the third class of 3-classes potential erosion risk map (Table 4). The results indicate that around 7% of Poland's terrestrial landscape should undergo anti-erosion meliora-

Table 3. The erosion risk reduction factor values for Corine CLC2000 land use classes.

Corine Land Cover land use classes				Reduction factor
No	Label Level1	Label Level2	Label Level3	
111	Artificial surfaces	Urban fabric	Continuous urban fabric	4
112			Discontinuous urban fabric	4
121		Industrial, commercial and transport units	Industrial or commercial units	5
122			Road and rail networks and associated land	5
123			Port areas	3
124			Airports	5
131		Mine, dump and construction sites	Mineral extraction sites	1
132			Dump sites	5
133			Construction sites	0
141		Artificial, non-agricultural vegetated areas	Green urban areas	3
142			Sport and leisure facilities	2
211	Agricultural areas	Arable land	Non-irrigated arable land	0
222		Permanent crops	Fruit trees and berry plantations	2
231		Pastures	Pastures	3
242		Heterogeneous agricultural areas	Complex cultivation patterns	1
243			Land principally occupied by agriculture, with significant areas of natural vegetation	1
311	Forest and semi natural areas	Forests	Broad-leaved forest	5
312			Coniferous forest	5
313			Mixed forest	5
321		Scrub and/or herbaceous vegetation associations	Natural grasslands	3
322			Moors and heathland	3
324			Transitional woodland-shrub	3
331		Open spaces with little or no vegetation	Beaches, dunes, sands	5
332			Bare rocks	5
333			Sparsely vegetated areas	0
334			Burnt areas	0
411 – 523	Wetlands and inlad waters			5

tions, i.e. kept under permanent crop cover. This affects the land with agricultural terrain with slope exceeding 10% as covered with risk of average to very strong water erosion intensities.

Comparing the potential and actual erosion risk maps with the Corine CLC 2000 land use classes, the source of the reduction of erosion risk becomes clearly visible (Table 6). The largest share in that reduction have sylvicultural and heterogeneous agricultural areas. This reflects the tendency to introduce protective land use types giving a permanent canopy cover on areas with high erosion risk, which is included in the Polish Code of Good Agricultural Practice [13], and well as being described in popular and scientific publications as a part of complex anti-erosional meliorations [2, 4] and land improvements [14].

Since the smallest scale of source data used in the analysis equals 1:300,000, the maps of actual water erosion risk should be considered at the same level of detail quality.

The results show far higher actual water erosion risk in Poland than those obtained by European erosion risk assessments. The difference comes both from the data quality as well as from different methodologies.

Table 4. Potential water erosion risk in Poland [12].

Erosion grade 5 classes	Erosion grade 3 classes	Explanation	Potential water erosion		
			Number of polygons	Area	
				Ha	%
0		no erosion		20,967,844	67.1
1	1	weak erosion	5212	4,775,015	15.3
2		moderate erosion			
3	2	average erosion	3730	3,693,926	11.8
4	3	strong erosion	752	1,479,384	4.7
5					
3-5	2-3	average to very strong erosion	4482	5,173,310	16.5
Sum			11,303	31,252,987	100

Table 5. Actual water erosion risk in Poland, based on CLC2000.

Erosion grade	Explanation	Minimal actual water erosion			Maximal actual water erosion		
		Number of polygons	Area		Number of polygons	Area	
			Ha	%		ha	%
0	no erosion		26,078,469	83.4		25,506,368	81.6
1	weak erosion	13,330	2,527,150	8.1	18,089	578,797	1.9
2	moderate erosion	12,063	421,754	1.3	25,152	2,939,808	9.4
3	average erosion	14,536	1,697,018	5.4	8761	1,380,543	4.4
4	strong erosion	3362	528,387	1.7	5856	318,875	1.0
5	very strong erosion	0	0	0.0	3362	528,387	1.7
3-5	average to very strong erosion	17,898	2,225,404	7.1	17,979	2,227,804	7.1
Sum		248,947	31,252,777	100	248,947	31,252,777	100

The data source of elevation used in most detailed pan-European studies [15-17], which is a 1km resolution DEM from EROS, cannot reflect the variability of terrain's relief, especially in upland and mountainous terrains [18], while the potential water erosion map produced in 1980 is based on 1:25,000 topographical, validated on 1:5,000 should give much better representation of the terrain relief. Moreover, the area of Poland, shaped by three glacial periods, is characterized by relative high variability of soil cover, which the scale of European soil map amounting to 1:1,000,000 could not represent in a satisfactory manner.

There are two main relatively detailed erosion assessments for Poland in context to European scale: USLE and PESERA. Both are model-driven approaches which cannot be easily compared with qualitative studies, although the initial comparisons between the Józefaciuks' qualitative indicators and results from physical modeling [6] show good correlation between these two diametrically different approaches. In lack of detailed data for comparisons between PESERA and the presented approach of actual erosion risk assessment (AWER) for Poland, a basic visual judgment reveals general spatial compatibility of areas threatened with erosion, although there is a large difference in the area of most severe erosion intensities in Polish mountainous areas. PESERA shows much lower share of severe erosion than AWER. This difference cannot be explained with the share of forest area since the AWER indicator assumes the area under forest as completely protected from water erosion (reduction factor equals to 5, hence AWER is always zero). One should remember that PESERA is based on 250m resolution grid of CORINE CLC1990, which has been later proven to be spatially incorrect and misclassified, which could affect the representation of land use classes. Another source of difference may be a different representation of soils' susceptibility to water erosion in both methods.

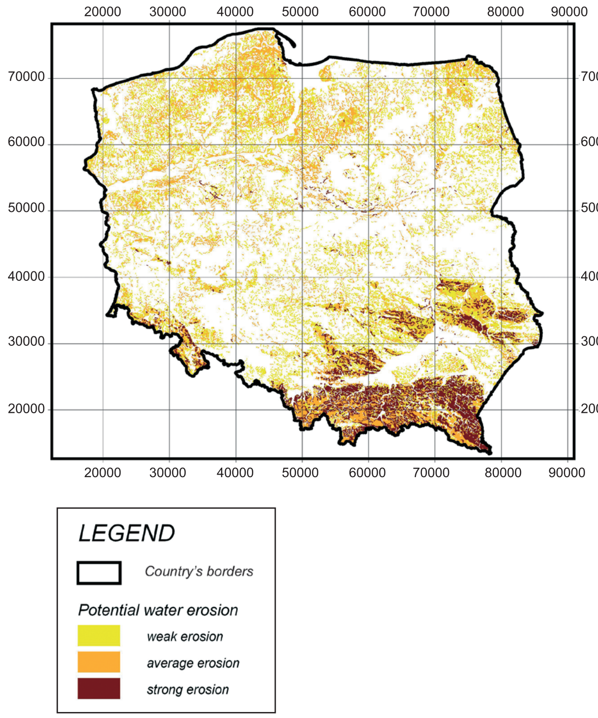

Fig. 1. Map of potential water erosion risk (PWER) [12].

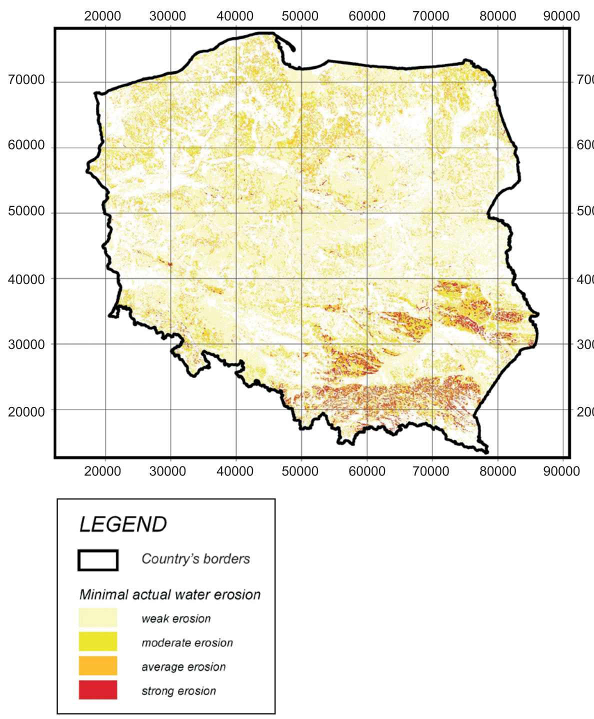

Fig. 2. The map of minimal actual erosion risk in Poland, based on Corine Land Cover 2000.

The legend of the published USLE map is less variable than PESERA and does not present good material even for visual comparisons.

CORINE Land Cover data remain the best available georeferenced national land use data for Poland. How-

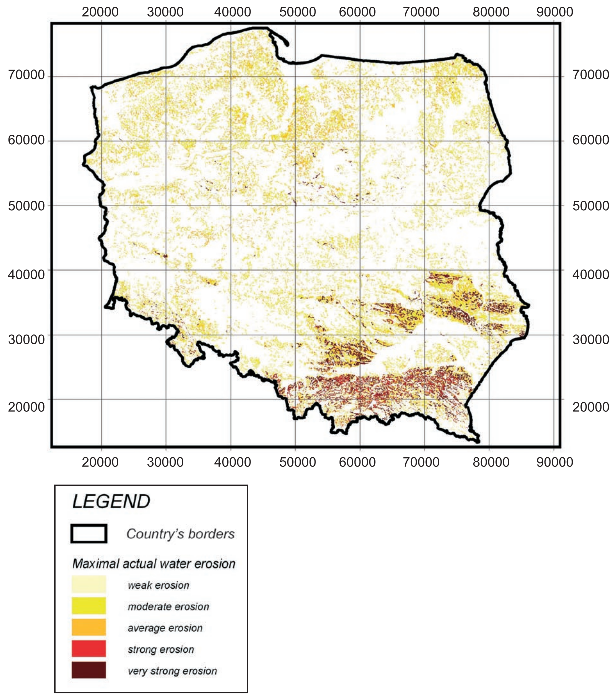

Fig. 3. The map of maximal actual erosion risk in Poland based on Corine Land Cover 2000.

ever, its present resolution corresponding to the scale 1:100,000, where linear elements smaller than 100m are not visible, cannot reflect the real state of land use structure in a satisfactory manner. Especially in the central, eastern and southern parts of Poland, characterized by small farms and dense structure of plots – so-called "chessboard of plots," where plots often have width less than 10m and are divided by a dense net of balks and afforestations, the current CLC introduces a large amount of uncertainty in the classification of land use. In those regions one should recalculate the AWER map using higher resolution land use data as, for example, classified scenes from Landsat TM or ASTER scenes, especially within already identified problem areas, than to improve CLC data, i.e. with statistical data from the National Statistical Survey, as presented by Erhard et al. [19] for the case in Germany. The Polish statistics for the rural sector are not reliable enough for landscape studies, based on out-of-date land ownership databases and rarely (approximately every 10 years) repeated national statistical surveys.

The recent analyses with use of slope data set derived from SRTM 90m DEM [10, 11] revealed far lower results than the discussed approach based on PWER map. Analyses of both potential (PWER) and actual (AWER) erosion risks based on SRTM DEM were several times underestimated, correspondingly 16.5% versus 3.5% and 7.1% versus 0.74%. These differences may come from the resolution of source data; however, the issue of scale and resolution has to be further investigated, including more detailed studies [5-7].

Table 6. The erosion risk at high grades (3-5) within Corine CLC classes.

Corine CLC code	Potential water erosion risk (PWER)	Actual water erosion risk (AWER)
	Percent of country's area	
	%	%
111	0.00	0.00
112	0.30	0.00
121	0.02	0.00
122	0.00	0.00
123	0.00	0.00
124	0.00	0.00
131	0.01	0.00
132	0.00	0.00
133	0.00	0.00
141	0.01	0.00
142	0.01	0.00
222	6.08	6.08
231	0.03	0.01
242	0.65	0.55
243	1.20	0.00
311	1.15	0.47
312	1.33	0.00
313	3.38	0.00
321	2.05	0.00
322	0.04	0.00
324	0.01	0.00
331	0.13	0.00
332	0.00	0.00
333	0.01	0.00
334	0.01	0.01
411	0.00	0.00
412	0.01	0.00
511	0.00	0.00
512	0.01	0.00
523	0.09	0.00

Presented AWER indicator should be considered as an indicator of state as defined by Gobin et al. [20]. Its relatively detailed resolution and good source data of potential erosion map and CORINE CLC2000 [9] provides good information for general policies at the regional level, supplementing a hitherto widely used map of potential erosion risk. However, it is not suitable for detailed studies on farm level or geodetic zone, which in Poland is equal to the extent of a village.

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