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Research paper

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Proposal for anti-erosion management of arable land in the Borowianka catchment area

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Summary

The paper calculates the magnitude of water erosion and proposes optimal scenarios for changes in agricultural space to reduce its degrading effects. Three assumptions were made based on the principles of good agricultural practices. The study used publicly available high-resolution thematic layers and analysed climatic conditions, physiographic conditions, land use structure, and agrotechnical work directions. The magnitude of water erosion was estimated based on the USLE equation. The individual parameters of the model were developed using methods of computerised spatial data analysis. The results showed that almost 75% of the catchment area was affected by water erosion (with an intensity ranging from 0,001 to 308,595 Mg $\cdot$ ha^{-1} $\cdot$ year^{-1}). Changing the direction of agricultural practices (from a slope-wise to a cross-slope arrangement) reduced soil loss by 13,64 Mg. Replacing corn and potatoes with spring oats and winter wheat reduced water erosion by 3,55 Mg. Simultaneous changes in field practices and crop selection reduced soil erosion by 15,85 Mg, while replacing some arable land with grassland reduced soil loss by 24,71 Mg, reducing the amount of soil material washed out of the field by as much as 73% compared to the baseline. The study showed that already adopting one anti-erosion measure, alongside good agricultural practices and measures to protect soil from water erosion can significantly reduce soil loss.

Keywords

USLE model • water erosion • land use

1. Introduction

Soil erosion by water is a complex and dynamic process involving the removal of the topsoil layer, causing a number of adverse changes in the environment [Jain et al. 2001, Mularz and Drzewiecki 2007], affecting many regions around the world and impairing the soil's ability to perform ecosystem services [Ferreira et al. 2024]. Soil erosion by water is one of the main threats to soils in the European Union, having a negative impact on ecosystem services and crop production [Panagos et al. 2014]. Over the last decade, erosion has become part of the environmental agenda in the European Union (EU) for the effects it has on food production, drinking water quality, ecosystem services, mudslides, eutrophication, biodiversity, and the depletion of organic carbon stocks [Boardman and Poesen 2006, Lugato et al. 2018]. The European Union has identified soil protection against erosion as one of its key priorities, estimating the annual financial costs at several billion euros. Soil erosion by water alone accounts for the largest soil losses in Europe compared to other erosion processes and costs European farmers 1.25 billion EUR annually [Panagos et al. 2018]. Membership in the European Union imposes on farmers the requirement to manage agricultural land in such a way as to counteract erosion, among other things. The need to protect the natural environment (including agricultural land) has forced our society to undertake intensive work aimed at improving its condition and preventing further degradation. These efforts have been driven by new environmental policies in Europe, such as the Thematic Strategy for Soil Protection [Montanarella 2015] and the Common Agricultural Policy. These policies take into account rapid changes in land use and the effects of climate change. The risk of erosion is particularly high in areas with poor agricultural management and where soils are left fallow or are inadequately maintained [Cerda et al. 2010]. Of all the factors influencing erosion, vegetation cover and agrotechnical practices are considered the most amenable to change. Therefore, detailed vegetation surveys can be crucial for achieving a realistic and accurate assessment of erosion. Despite the abundance and use of water erosion models, selecting the appropriate model for operational mapping remains a significant challenge. The widespread use of geographic information systems (GIS) and the use of remote sensing data have greatly accelerated erosion modeling. The most commonly used erosion model is the USLE (Universal Soil Loss Equation) model [Wischmeier and Smith 1978]. This model combines natural and anthropogenic factors affecting erosion, while taking into account conditions resulting from pedological, physiographic, and meteorological factors, vegetation cover, and the course of agrotechnical works. When determining areas at risk, areas covered by forests are regarded as secured against erosion. This task is fairly easy to carry out for small areas, but becomes very complicated for large areas, where detailed analysis of even the agricultural structure becomes difficult to perform. In mountainous areas in Central Europe, the main factors contributing to erosion appear to be slope steepness and spatial land use patterns [Kliment et al. 2008]. In regions with varied terrain (mountainous areas, foothills, highlands, and lake districts), erosion control basically comes down to changing the way the catchment area is used. The nature of the Polish agricultural land ownership structure is reflected in the high fragmentation of individual fields, which has a direct bearing on the difficulties in introducing agrotechnical anti-erosion measures [Orlik 2002]. In the Pogórze Wiśnickie catchment area, agrotechnical measures and cultivation are predominantly carried out in accordance with the slope gradient.

The study conducted an inventory of the Borowianka stream catchment area in terms of its exposure to water erosion. In order to minimise soil loss, it proposed optimal scenarios for changes in agricultural land based on the principles of good agricultural practice and protective measures.

2. Subject and methodology

The study area included the small agricultural catchment area of the Borowianka stream, located in the Wiśnickie Foothills (Małopolskie voivodeship) in the Bochnia county, Nowy Wiśnicz municipality (N:49°54´43.87´´, E:20°32´52.87´´). The total area of the catchment, determined by GIS methods, is 10.3 km². The studied area is a region with soils characterised by factors conducive to water erosion, i.e., varied relief (Fig. 1) and slope exposure (Fig. 2), locally with high slopes and soil highly susceptible to leaching.

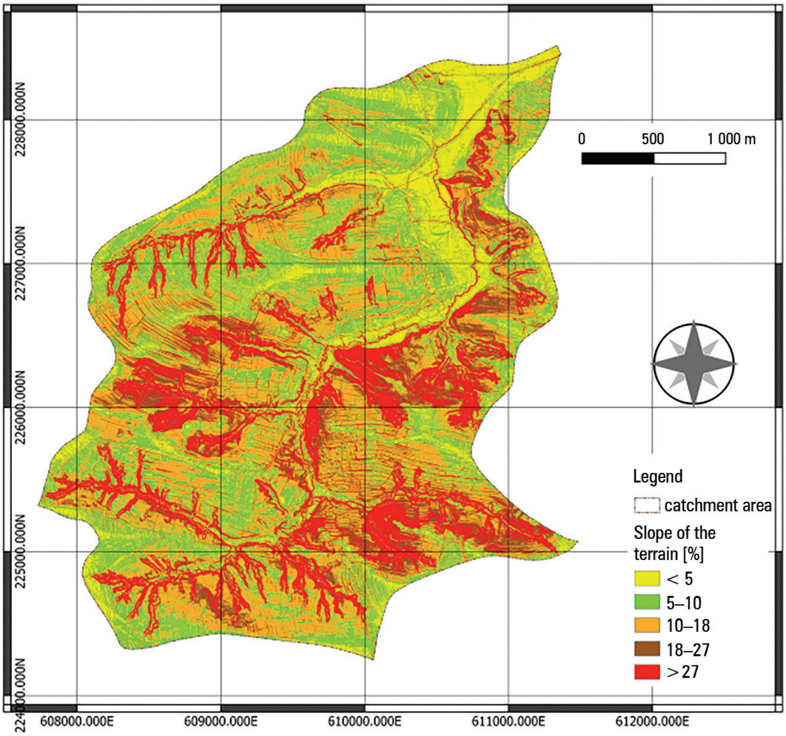

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Fig. 1. Slope of the terrain [%]

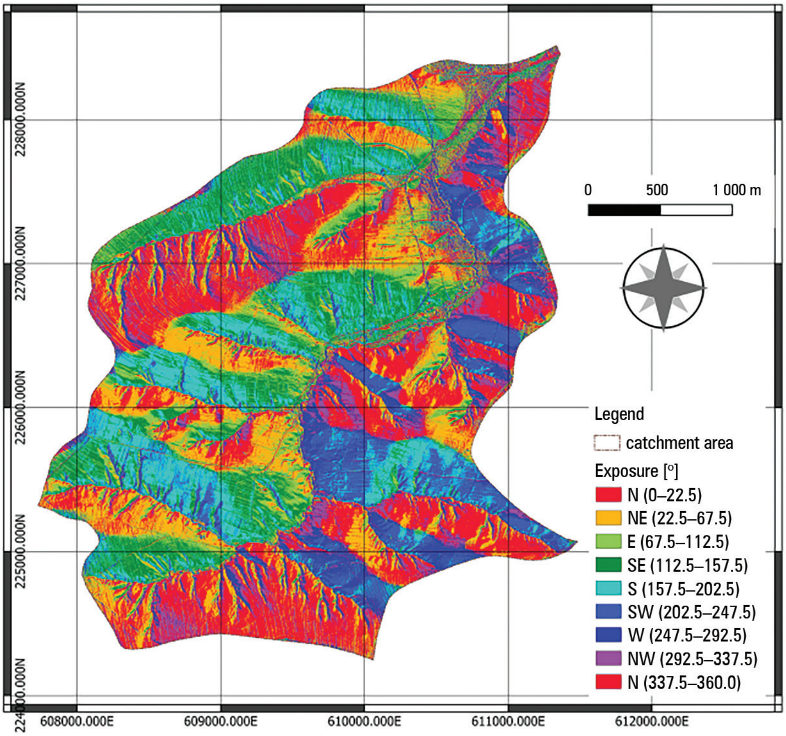

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Fig. 2. Slope exposure [°]

The predominant soil types are loess and loam soils. In the central part, there are areas with clays (Fig. 4). The land use structure is dominated by woodlands (44.9%) and grasslands (31.8%), and the main crops on arable land (accounting for 15.44%) are: potatoes (5.3%), winter wheat (5.1%), grain maize (3.7%), spring oats (1.0%) and beetroot (0.11%) (Fig. 3 and Fig. 5).

This area is severely degraded by water erosion processes. Under constant anthropogenic pressure, such as frequent, incorrect agrotechnical practices on arable land from the point of view of erosion prevention, and faulty crop management, the soil is washed away from the slopes towards the erosion base. The effects of erosion can be observed both on the slopes and at their foot (Fig. 6).

The study inventoried the area with regard to its exposure to water erosion on agricultural land and proposed optimal scenarios for changes in the agricultural space. The scenarios for the proposed changes were developed based on good anti-erosion practices and agri-environmental measures for soil protection. The study took into account a change in the method of agrotechnical treatments (scenario 1), a change in the selection of crop species (scenario 2), a combination of scenarios 1 and 2 (scenario 3),

Photos by Edyta Kruk

Fig. 3. Land use, from the left: potatoes, winter wheat, spring oats, grain maize

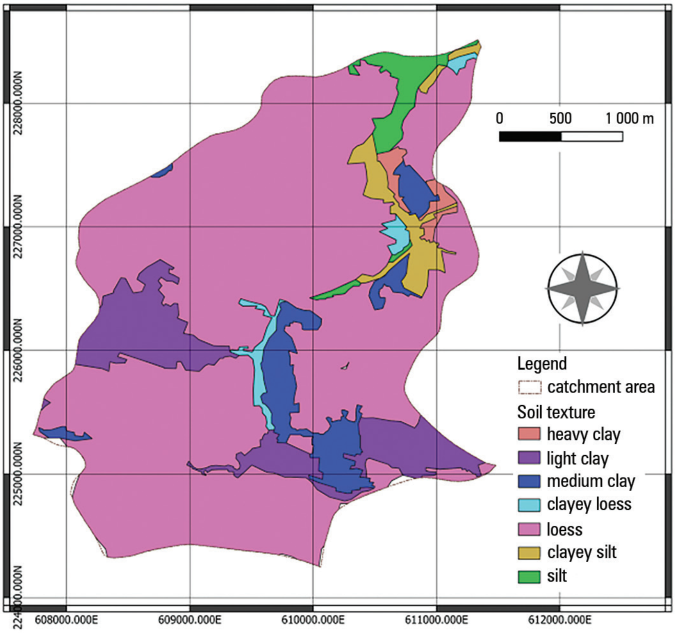

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Fig. 4. Soil texture

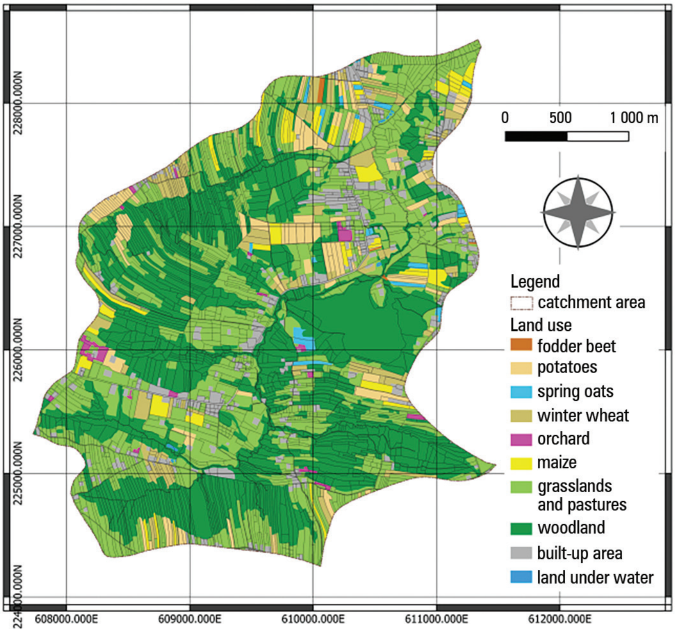

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Fig. 5. Land use

Photos by Edyta Kruk

Fig. 6. Surface runoff from potato fields (left) and maize fields (right) after rainfall on 9 July 2025

and a combination of scenario 3 with the replacement of some crops with grassland (scenario 4). The research involved the implementation of integrated analytical and modelling GIS tools based on a digital terrain model of the Borowianka catchment area. The study used publicly available high-resolution thematic layers (such as data from KRON86 laser scanning with a resolution of 1x1 m). Natural (climate, terrain, soil cover) and anthropogenic factors (type of crops and direction of agrotechnical work) that determine the character and extent of erosion were taken into account. An important element of the study was an on-site inspection carried out on 9 July 2025. The extent of water erosion was estimated on the basis of the niversal soil loss equation (USLE) [Wischmeier and Smith 1978] using the following formula:

$$E = R \cdot K \cdot L \cdot S \cdot C \cdot P$$

where:

- E – the amount of soil displaced from a unit area in a given time [$Mg \cdot ha^{-1}$],
- R – the rainfall and surface runoff erosion coefficient [$MJ \cdot mm \cdot ha^{-1} \cdot h^{-1}$],
- K – the soil erosion coefficient [$Mg \cdot ha \cdot h \cdot MJ^{-1} \cdot ha^{-1} \cdot mm^{-1}$],
- L – the slope length coefficient [–],
- S – the slope gradient coefficient [–],
- C – the crop type and land use coefficient [–],
- P – the agrotechnical erosion control measures coefficient [–] [Panagos et al. 2014, Kruk et al. 2025].

The above parameters were developed using methods of computer analysis of spatial data (including satellite images and digital elevation models, DEM). The algorithms used in the development of component data and input parameters are presented in Table 1.

The rainfall erosion coefficient and runoff coefficient R were determined on the basis of DEM using the correlation developed by Licznar [2006] between altitude above sea level (h) and precipitation for local conditions in Poland.

Table 1. Input parameters, processes and data sources used in the USLE model

Erosion parameter	Equation	Input parameter	Operation required	Data source	URL
R	R = 0.0709 · h + 49.246	height *h*	using the relationship between DEM elevation and precipitation [Licznar 2006]	DEM elevation model	https://www.geoportal.gov.pl/pl/dane/numeryczny-model-terenu-nmt/
K	subgroup / OMC > 2%	granulometric subgroup	conversion of granulometric groups according to the USDA standard [Stone and Hilborn 2012]	soil map of Poland	https://www.iung.pl/informacje/ofe rta/pracekartograficzne/
	clay: heavy 0.063 light 0.027 medium 0.045 loess 0.083	OMC [%]	organic matter content	monitoring of soil chemistry in Poland (IUNG)	https://www.gios.gov.pl/chemizm_gleb/index.php?mod=wyniki&cz=C
L	$L_{(i,j)} = \frac{\left(A_{i,j} + D^2\right)^{m+1} - A_{i,j}^{m+1}}{x^m \cdot D^{m+2} \cdot (22{,}13)^m}$	raster resolution D, catchement area Ai,j	algorithm D8, runoff course	DEM elevation model	https://www.geoportal.gov.pl/pl/dane/numeryczny-model-terenu-nmt/
S	10.8 · sinθ + 0.3 for tanθ < 0.09 16.8 · sinθ – 0.5 for tanθ ≥ 0.09 · [McCool et al. 1989, Renard et al. 2001]	sinθ	slope gradient [%]		
C	$C = C_a \cdot C_b$	type of use, agrotechnical treatments	roots (0.50) meize (0.40) winter and spring wheat (0.35) orchards (0.10) grassland (0.02) autumn ploughing (1,00) [Stone and Hilborn 2012]	orthophotomap, site inspection dated 9 July 2025	https://mapy.geoportal.gov.pl/imap/Imgp_2.html?gpmap=gp0
P		crop orientation	longitudal (1.00) cross-slope (0.75) perpendicular (0.37) [Stone and Hilborn 2012]		

Direct measurements of the soil susceptibility to erosion coefficient *K* (determining the response of the soil profile to the process of soil particle detachment and transport under the influence of raindrops and runoff [Renard et al. 1997] in situ are very time-consuming. Therefore, the most commonly used methods for determining the coefficient are nomograms. The study used the method proposed by Stone and Hilborn [2012], improved by a correction factor for organic matter content (OMC) [%]. The value of the *K* parameter was estimated based on information on soil texture according to USDA [2002]. Structural groups were developed based on a soil map at a scale of 1:25,000. The organic matter content was derived from soil chemistry monitoring in Poland (Monitoring Chemizmu Gleb Ornych [Monitoring of Arable Land Chemistry], gios.gov.pl). Point 425, located in Łapczyca, Bochnia county, with an OMC value > 2%, was taken as the reference point.

The slope length coefficient *L* and slope gradient (*S*) were calculated based on the algorithms developed by McCool et al. [1989], which take into account the resolution of the raster DEM map (*D*), the unit catchment area ($A_{i,j}$), the slope length index exponent (*m*), and the terrain slope [%].

The value of the crop type coefficient and land use coefficient *C* for agricultural crops depends on the species of the cultivated plant and the basic method of cultivation. This parameter was estimated on the basis of land use maps generated from satellite images verified during field surveys (Fig. 9). Land use was illustrated as a parameter expressing the impact of land use types (C_a) and the type of agrotechnical measures applied (C_b). The empirical values of land use parameters were calculated in accordance with the values specified by Stone and Hilborn [2012].

The impact of anti-erosion practices, i.e. the agrotechnical measures that mitigate soil erosion (parameter *P*), was determined based on the orientation of the crop in relation to the steepest slope [Stone and Hilborn 2012].

The classification of the obtained water erosion results was based on the system adopted in the PESERA project, which defines erosion risk maps for Europe [Karydas et al. 2015], taking into account the following ranges: 0.01–0.50, 0.50–1.00, 1.00–2.00, 2.00–5.00, 5.00–10.00, 10.00–20.00, > 20.00 Mg · ha^{-1} · year^{-1} due to favorable conditions for erosion (steep slopes, soils), modified by the introduction of additional ranges 20.00–50.00 and > 50.00 Mg · ha^{-1} · year^{-1} [Kruk et al. 2025].

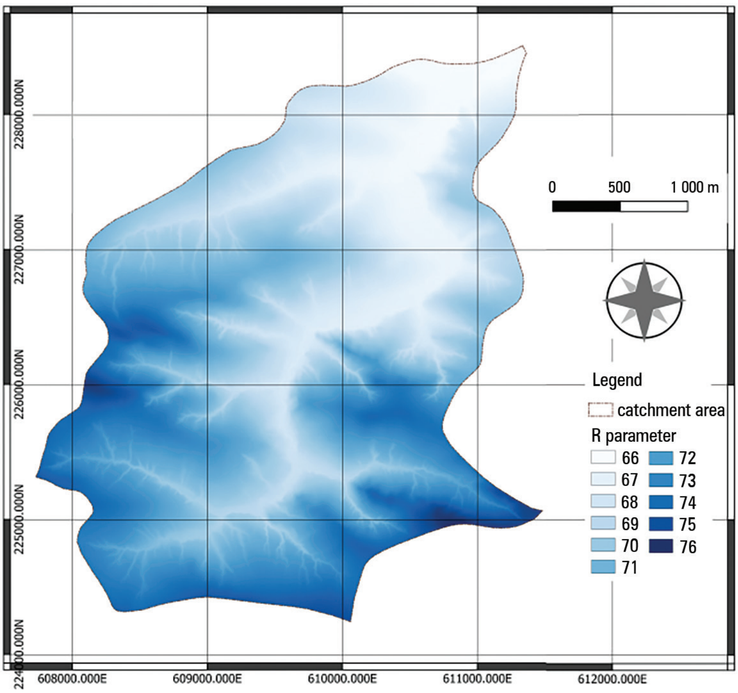
3. Results and summary

The rainfall and runoff erosion coefficient R, determined on the basis of the correlation between altitude above sea level (*h*) and precipitation for local conditions in Poland, ranged from 66.23 to 76.11 MJ · mm · ha^{-1} · h^{-1} (Fig. 7). The average value was 70.60 MJ · mm · ha^{-1} · ha^{-1} and the standard deviation was 2.362.

Clay formations show lower values of the soil susceptibility coefficient *K* due to their high resistance to particle detachment when exposed to water. Dust and loess soils, on the other hand, show higher values of the coefficient due to their low resistance to water erosion caused by their structure and properties. The studied area was dominated by soils that were highly susceptible to water erosion (coefficient value of 0.083 Mg · ha · h · MJ^{-1} · ha^{-1} · mm^{-1}), which covered 82.47% of the catchment area. Clay formations (light clay 0.027, medium clay 0.045, heavy clay 0.063) covered 10.44%, 6.01%, and 1.08% of the area, respectively (Fig. 3). The average value of the *K* parameter was 0.075 Mg · ha · h · MJ^{-1} · ha^{-1} · mm^{-1}. The minimum value was 0.027, and the maximum value was 0.083 Mg · ha · h · MJ^{-1} · ha^{-1} · mm^{-1}. The standard deviation was 0.019.

The slope length coefficient L ranged from 0.098 to 246.589 [-]. The mean value was 1.564 [-] and the standard deviation was 4.416, while the slope coefficient (*S*) values ranged from 0.00 to 14.288 [-]. The average value was 1.464 and the standard deviation was 2.076.

The catchment area is characterised by traditional crop cultivation, with the predominant use of winter ploughing (parameter value Cb 1.00). The land use structure is dominated by wooded areas and grasslands (meadows and pastures) (Ca 0.02), and the crops included winter wheat (Ca 0.35), grain maize (Ca 0.40), spring oats (Ca 0.35), potatoes (Ca 0.50) and sugar beet (Ca 0.50). Fruit orchards (Ca 0.10) were also inventoried in the catchment area (Fig. 4). The values of the coefficient C of crop type and land use for agricultural crops ranged from 0.02 to 0.50 [–], with an average value of 0.08 [–] and a standard deviation of 0.146. The majority of arable land has coefficients of 0.35 (38.0%), 0.40 (23.3%) and 0.50 (33.7%).



Source: Author's own study

Fig. 7. Rainfall and runoff erosion coefficient *R*

During the field survey, the spatial distribution of individual types of land use and the direction of agrotechnical treatments were highlighted. Three methods of agrotechnical treatment were identified: up and down the slope (P 1.00), angled (P 0.75) and cross-slope (0.37). Due to the layout of the plots (long and narrow), the dominant method of cultivation was along the runoff line (Fig. 8). This necessitates the use of extremely unfavourable longitudinal slope cultivation. The agrotechnical treatments used in such a field layout accelerate and intensify erosion. The average value of the *P* parameter was 0.86 [–]. The minimum value was 0.37 and the maximum value was 1.00 [–]. The standard deviation was 0.163.

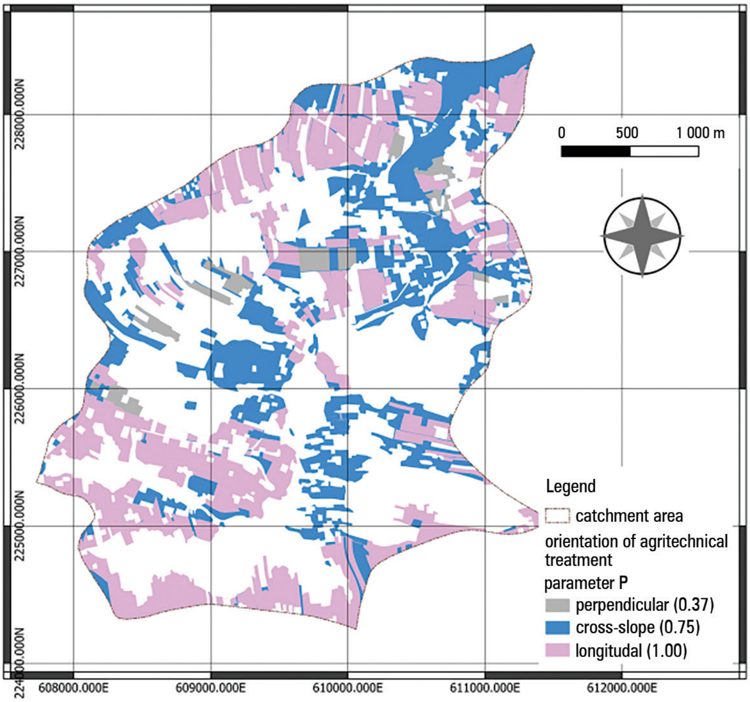


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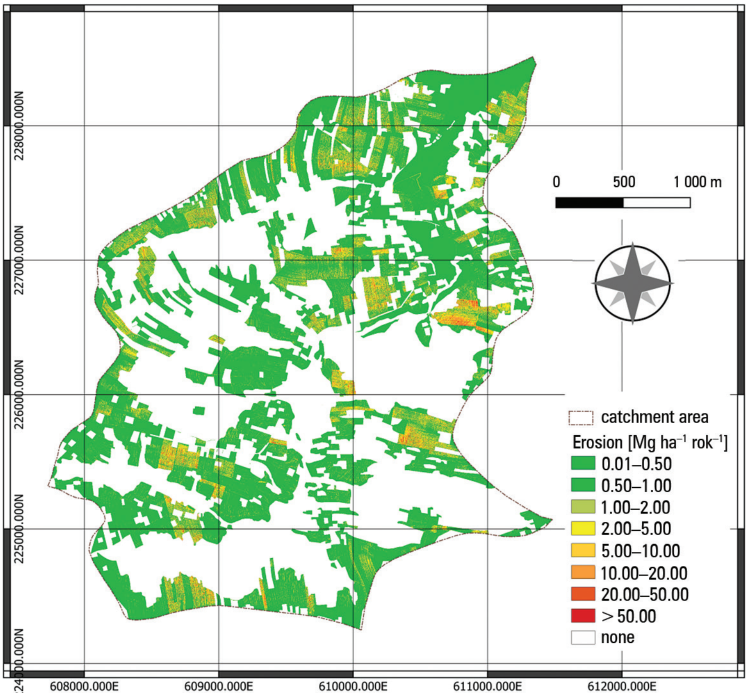
Fig. 8. Coefficient of erosion control measures related to agricultural technology *P*

The analysis showed water erosion on an area of almost 8 km² (7.73). Areas where no erosion processes were observed included built-up areas and woodland (Fig. 9). Approximately 40% of the area fell within the erosion range of less than 1.00 Mg · ha^{-1} · year^{-1} and 1.00–5.00 Mg · ha^{-1} · year^{-1}. Erosion values > 20.00 Mg · ha^{-1} · year^{-1} occurred in an area of approximately 10%. The average soil loss was 1.251 Mg · ha^{-1} · year^{-1} and the standard deviation was 5.953. The minimum value was 0.001 Mg · ha^{-1} · year^{-1}, while the maximum was 308.595 Mg · ha^{-1} · year^{-1}. Detailed distribution of erosion values (in ranges):

- 0.01–0.50 Mg · ha^{-1} · year^{-1}: 17.66%
- 0.50–1.00 Mg · ha^{-1} · year^{-1}: 21.89%
- 1.00–2.00 Mg · ha^{-1} · year^{-1}: 20.69%
- 2.00–5.00 Mg · ha^{-1} · year^{-1}: 20.65%
- 5.00–10.00 Mg · ha^{-1} · year^{-1}: 9.32%
- 10.00–20.00 Mg · ha^{-1} · year^{-1}: 5.22%
- 20.00–50.00 Mg · ha^{-1} · year^{-1}: 3.40%
- > 50.00 Mg · ha^{-1} · year^{-1}: 1.17%.

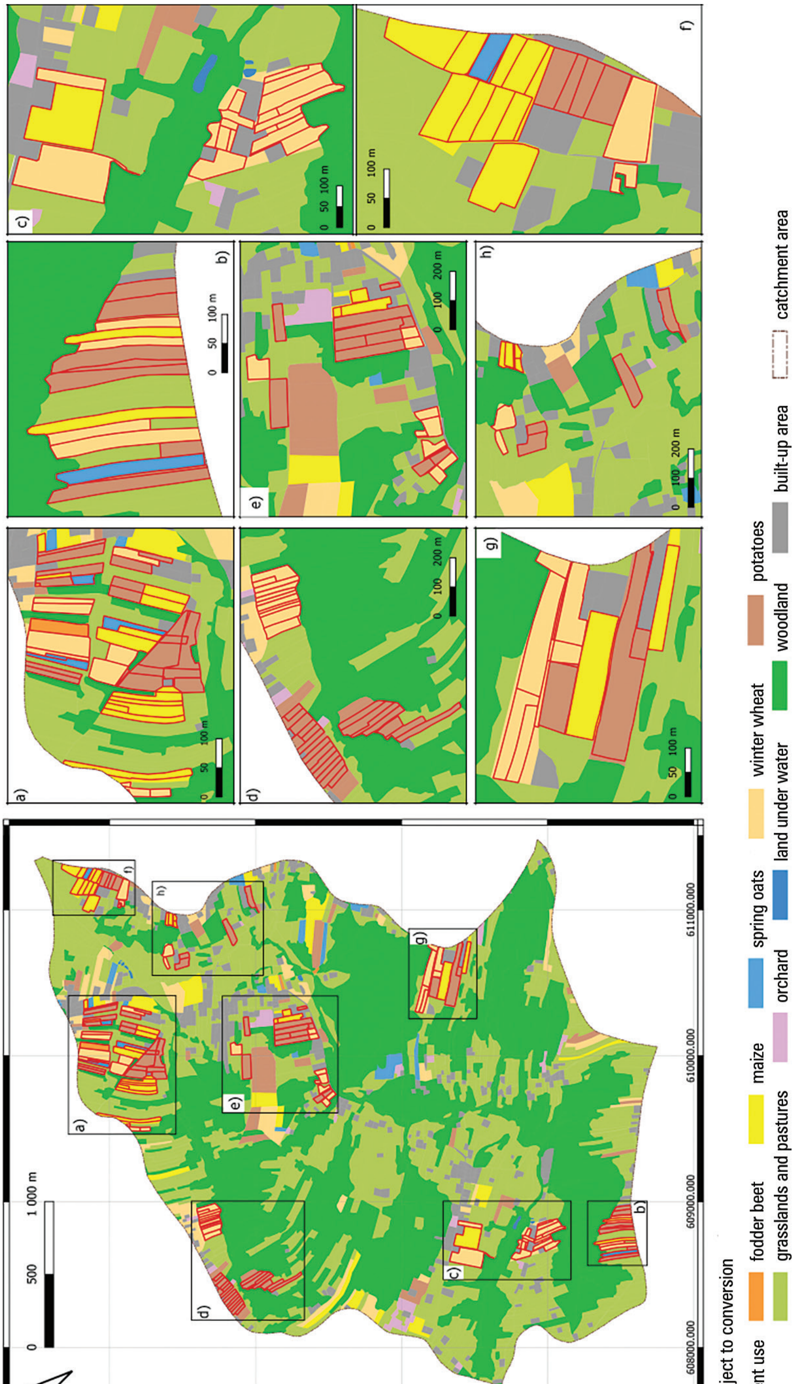


Source: Author's own study

Fig. 9. Map of water erosion in the Borowianka catchment area

The areas most at risk of water erosion were identified after a detailed analysis of the map. The rest of the study focused on agricultural land, dividing it into eight areas (Fig. 10 a–f).

The results of the analyses presented above were used to develop scenarios for comprehensive agri-environmental measures aimed at reducing water erosion on arable land. The first scenario assumed only a change in the orientation of agrotechnical work (change in parameter *P*) while retaining existing crops. In the second scenario, only the crop structure was changed by replacing plants with a higher *C* coefficient with cereal



Source: Author's own study

Fig. 10. Land subject to conversion

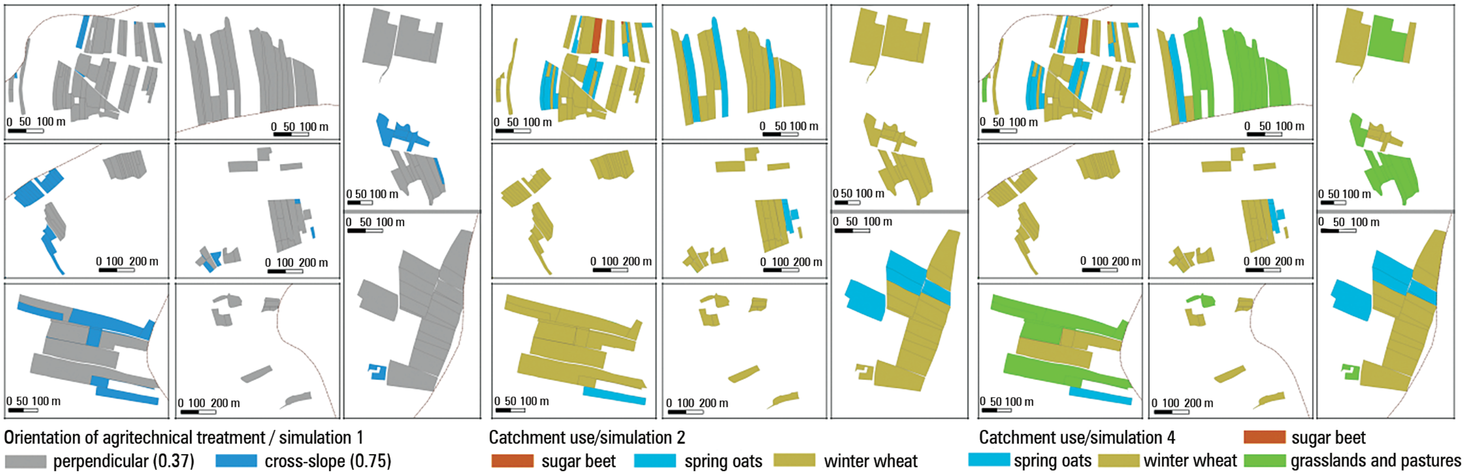
crops (with a lower *C* value). The third scenario assumed a change in the orientation of agrotechnical work as well as a change in the crop structure (as in the second scenario). In the last, fourth scenario, grassland was introduced on land where erosion remained high despite the earlier changes (Fig. 11). The proposed agri-environmental measures were chosen to suit local conditions and developed in accordance with the Code of Good Agricultural Practice. The proposed measures comply with European standards for sustainable management and environmentally friendly agricultural production. The proposed changes in the nature of agricultural production concerned, among other things, issues related to the method of cultivation and the structure of agricultural land. The proposals included: the use of cross-slope cultivation, especially on long slopes, and ploughing with turning of the furrow, the selection of appropriate plants to protect the soil from the leaching of soil particles, fertilisers and plant protection products. All planning proposals were illustrated using ArcGIS software and presented in the form of a cartographic study.

The area of eroded soil material (in km²) in individual erosion groups in the adopted simulations and total erosion [Mg] are presented in Figure 12 and Table 2.

Table 2. Scenarios for comprehensive agri-environmental measures ($Mg \cdot ha^{-1} \cdot year^{-1} / km^2$)

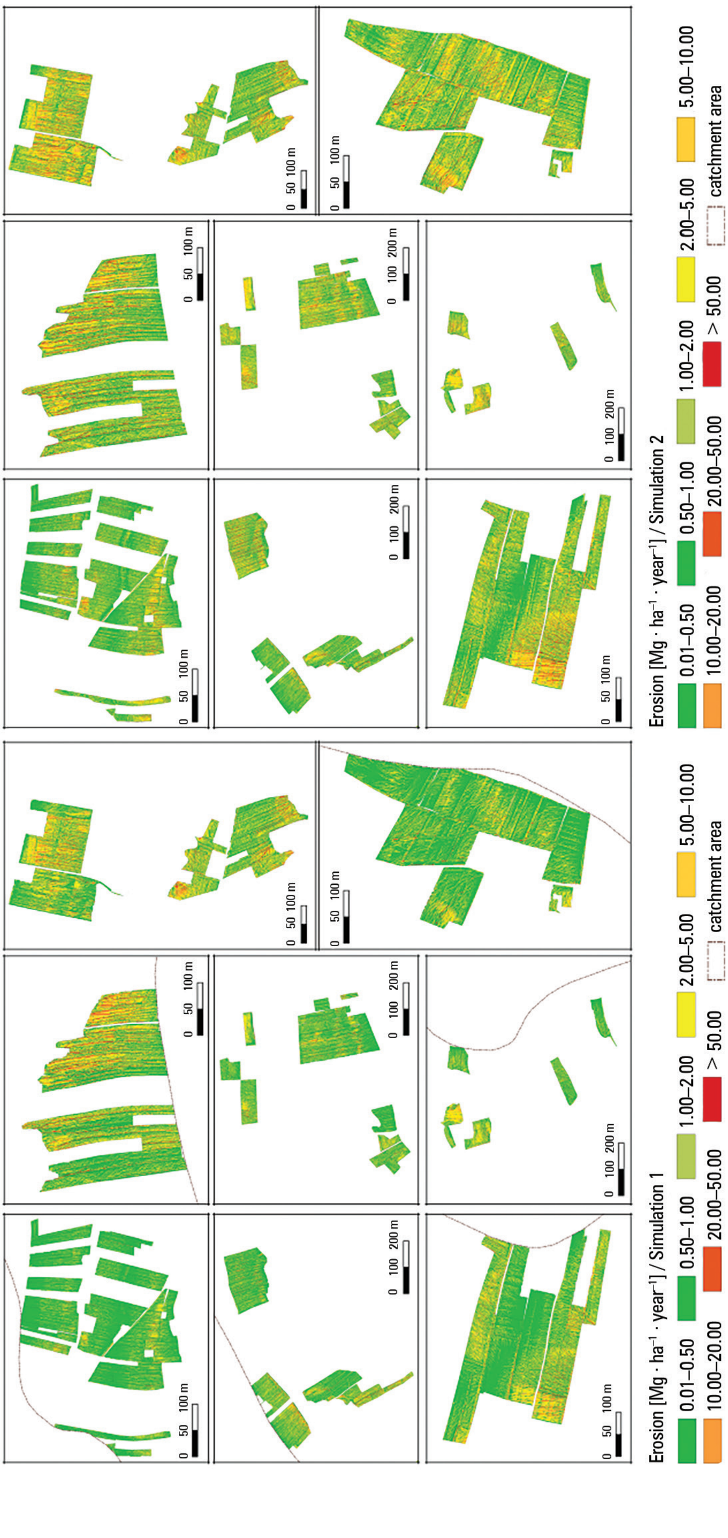
Extent of erosion $Mg \cdot ha^{-1} \cdot rok^{-1} / km^2$	Erosion initial situation	Simulation 1	Simulation 2	Simulation 3	Simulation 4
0,01–0.50	1.36	3.04	1.73	3.39	4.84
0.50–1.00	1.69	1.52	1.63	1.47	1.15
1.00–2.00	1.60	1.24	1.59	1.18	0.86
2.00–5.00	1.60	1.06	1.49	0.96	0.56
5.00–10.00	0.72	0.46	0.62	0.37	0.19
10.00–20.00	0.40	0.22	0.35	0.19	0.06
20.00–50.00	0.24	0.13	0.22	0.11	0.03
>50.00	0.09	0.03	0.07	0.03	0.01
Total erosion [Mg]	33.91	20.27	30.36	18.06	9.20

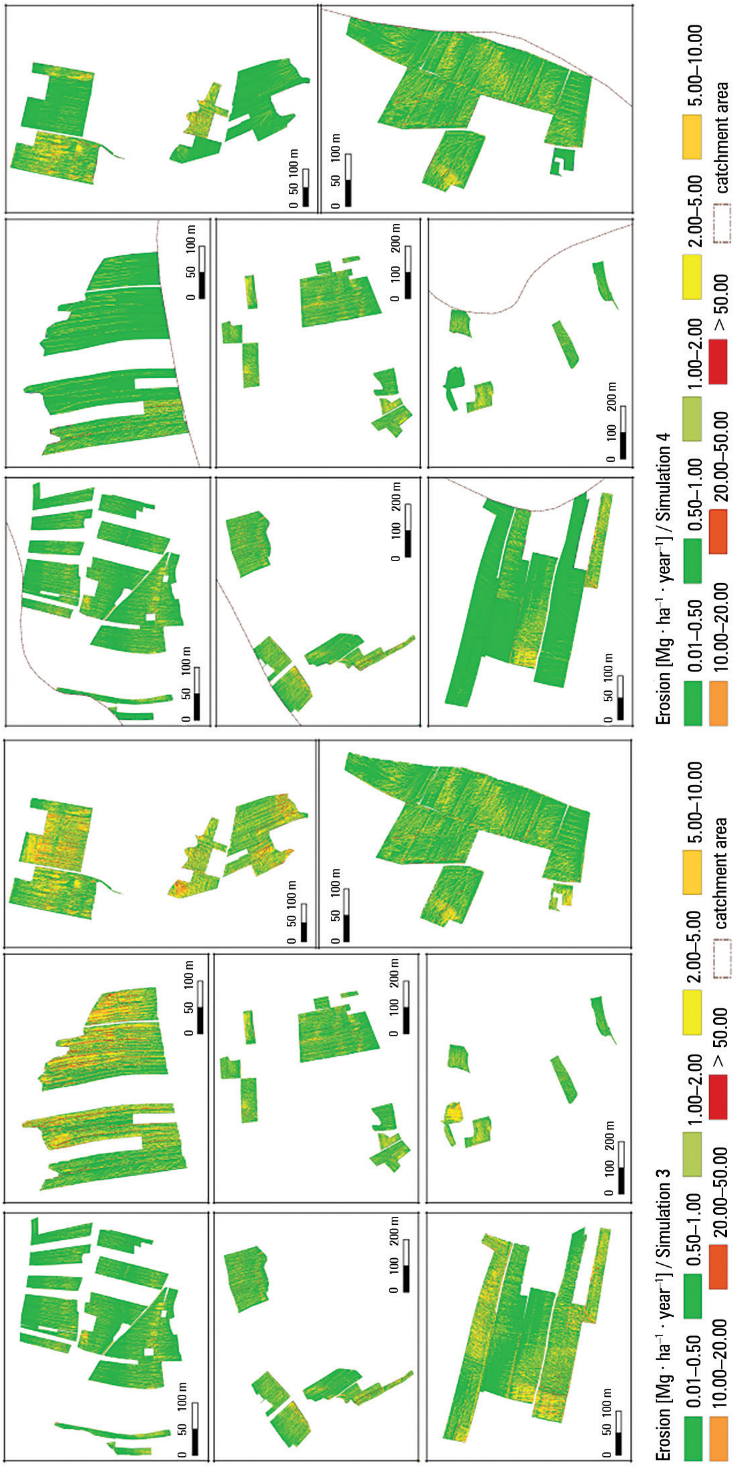
When analysing the obtained results, it should be noted that already the change in the orientation of agrotechnical measures from a longitudinal to a cross-slope arrangement reduces the area at risk of severe and very severe erosion (> 20.00 $Mg \cdot ha^{-1} \cdot year^{-1}$) and increases very low erosion (< 1.00 $Mg \cdot ha^{-1} \cdot year^{-1}$) by about 50% in both ranges, and causes a reduction in soil loss by 13.64 Mg. The introduction of changes in the crop structure (replacing maize and potatoes with spring oats and winter wheat) resulted in a reduction in the area at risk of severe and very severe erosion (> 20.00 $Mg \cdot ha^{-1} \cdot year^{-1}$) by approximately 12% and an increase in very weak erosion (< 1.00 $Mg \cdot ha^{-1} \cdot year^{-1}$) by approximately 10% and a reduction in soil loss by 3.55 Mg. Changes in both agrotechnical practices and crop structure (as in scenario two) resulted in



Source: Author's own study

Fig. 11. Assumptions adopted for soil loss simulation


Erosion [Mg · ha⁻¹ · year⁻¹] / Simulation 1
0.01–0.50
0.50–1.00
1.00–2.00
2.00–5.00
5.00–10.00
10.00–20.00
20.00–50.00
> 50.00
catchment area
Erosion [Mg · ha⁻¹ · year⁻¹] / Simulation 2
0.01–0.50
0.50–1.00
1.00–2.00
2.00–5.00
5.00–10.00
10.00–20.00
20.00–50.00
> 50.00
catchment area
0 50 100 m
0 100 200 m



Source: Author's own study

Fig. 12. Water erosion in intervals, in the adopted scenarios

a reduction in the area at risk of severe and very severe erosion (> 20.00 Mg · ha^{-1} · year^{-1}) by approximately 40%, and an increase in very low erosion (< 1.00 Mg · ha^{-1} · year^{-1}) by about 60%, as well as a reduction in soil loss by 15.85 Mg. On the other hand, the introduction of grassland on land where erosion remained high despite the earlier changes resulted in a reduction in the risk of severe and very severe erosion (> 20.00 Mg · ha^{-1} · year^{-1}) by approximately 88%, and an increase in very weak erosion (< 1.00 Mg · ha^{-1} · year^{-1}) by approximately 95%. It also led to a reduction in soil loss by 24.71 Mg, which represents a reduction in soil material washed away from arable land by as much as 73% compared to the current situation.

The simulations showed that following good agricultural practices in field work on arable land, and implementing measures to protect the soil from water erosion, makes it possible to reduce soil loss from farmland even when only one erosion factor is changed (scenarios 1 and 2). Although there is a noticeable shift in soil loss towards lower erosion groups, simulation 3 showed that, due to the terrain and slopes, it is necessary to introduce grassland on some arable land. Only this treatment gives satisfactory results. The direct studies and spatial analyses carried out in the classification of the catchment area in terms of the urgency of erosion protection are a sufficient tool.

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