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The Importance of Environmental Factors for the Development of Water Erosion of Soil in Agricultural Land: The Southern Part of Hronská Pahorkatina Hill Land, Slovakia

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Abstract: The water erosion research was carried out in the lowland type of hilly landscape. The aim was to monitor and evaluate the importance of environmental factors (steepness of slope, relief shapes, aspect, slope length, combination slope length (L) and slope (S)—LS factor, types of land use changes) for the development of water erosion. We focused on the identification of areas threatened by erosion by interpreting aerial photographs from several time periods. This was followed by verification of erosion using soil probes. We identified 408.44 ha of areas affected by erosion, and measured the depth of soil and "A" horizons thickness. The environmental factors were modeled in geographical information systems by tools for spatially oriented data. Subsequently, the influence and significance of individual environmental factors were compared, and the probability of erosion was statistically estimated. The decisive factors in the formation of erosive surfaces are the LS factor and the slope. We also consider the factor of the relief shape to be important. The shape did not appear to be very significant as a separately evaluated factor, but all convex parts correlate with the identified erosion surfaces. The susceptibility of erosion related to the aspect of the slopes to the cardinal directions has not been confirmed. Types of land use changes with the most significant relation of erosion were confirmed in areas of strong intensification. We confirmed the importance of factors and land use for the development of erosion processes.

Keywords: erosion identification; modelling of erosion processes; relief properties; significance of factors; slope; land use

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1. Introduction

In Slovakia, almost half of the area of agricultural land is threatened by erosion. Due to erosion of the surface, most of the fertile horizon of the soil is lost. It is dominated by water erosion of the soil, which currently threatens almost 40% of agricultural land. Eroded soils are found mainly on the slopes of lowland hills. The hills in the lowland regions of Slovakia are intensively used agricultural areas with a high proportion of arable land and are at the same time areas with the highest risk of erosion and soil loss.

The study focuses on the processes of water erosion, which can be observed in the conditions of Slovakia, especially in the hills, which have suitable climatic and soil conditions for agricultural use. Water erosion processes are considered to be a serious problem of soil degradation. Erosion changes the properties of the soil, food production, drinking water quality, ecosystem services, eutrophication, biodiversity, carbon stock shrinkage, and causes mud floods [1–3]. They are of great importance in the modelling of the relief landscape [4] as well as in the degradation of the fertile properties of agricultural soils. They are manifested by a reduction in the depth of the soil profile, a loss of organic matter and nutrients, as well as a deterioration of the soil structure [5]. From the point of view of the long-term negative effect on soil properties, water erosion is perceived as a significant environmental threat. Although water erosion is a natural process, in the intensively used land it is significantly accelerated by inconsiderate human activity [6]. Human interventions in the natural environment affect the natural erosion processes [7], as man works mainly by destroying natural vegetation, growing crops with a low soil protection effect, exposing the soil, increasing, and concentrating surface drain, changing soil properties during intensive agricultural activity, etc. Given these risks, soil protection and care should be one of the priorities from the global to the local level [8], which depends on the social and political conditions of the countries. For the successful application of the principles of soil erosion protection, it is therefore necessary to adapt the concept of protection to social and economic conditions in practice. The need to protect the soil from water erosion is determined based on an assessment of the erosion risk to agricultural land. It is based on normative principles and rules of soil protection at the national and international level. The EU Member States are required to adopt a comprehensive approach to deal with soil erosion. One of the steps is the identification of risk areas, the development of a methodology for risk reduction and the elaboration of programs of measures to achieve the elimination of erosion processes.

The effective and comprehensive protection of soil against erosion is based on knowledge of the conditions in which it occurs. Therefore, there is a growing need for more detailed research of the factors that influence its development.

The aim was to monitor and evaluate the importance of selected environmental factors for the development of water erosion in the hilly type of landscape. Despite long-term research and the amount of knowledge using modern tools to simulate and model environmental threats, soil degradation caused by water erosion is a common phenomenon, especially in the lowland hills of Slovakia. The model area was an intensively used agricultural landscape with manifestations of water erosion in Hronská pahorkatina hill land, where despite massive manifestations of soil erosion, systematic research on soil erosion has not yet been realized. Large blocks arable land with significant visual manifestations of soil erosion predominates there.

1.1. Environmental Factors Supporting the Development of Erosion

The origin, course, and intensity of erosion processes are influenced by primary factors, which are not caused or influenced by human activity. They are also influenced by secondary factors, in the formation of which man is involved. They are similarly structured in works by Wischmeier and Smith [9], Morgan [10], Petlušová et al. [11], Rodrigo-Comino et al. [12], Gao et al. [13], and Ahmed et al. [14]. This paper evaluates the importance of primary factors—slope (steepness of slope), relief shape, aspect, slope length, LS factor (a combination of slope length and slope), and secondary changes in land use.

1.1.1. Primary Factors

The slope and slope length affect the speed and amount of drainage [15]. Authors [16–20] state that the greater the slope, the greater the speed, drag force, and energy of the effluent water. They consider the so-called critical slope to be a significant indicator. Of the seasonal erosion phenomena, the slope at which the rills begin to form (rill erosion) is considered to be critical. Zachar [21] states that in the case of surface erosion, the critical slope ranges from 1 to 8°, in slope grooves from 2.5 to 16°, and in valley grooves from 1 to 6°. Slopes, as one of the most important features of the relief, are part of proposals for optimizing the use of agricultural land under the Common Agricultural Policy of the EU. The intensity of erosion is influenced by the slope length, which is defined as the distance from the water divide, at which the surface drain changes to concentric, i.e., at which the surface erosion changes to washout erosion, or where erosion reaches the value of allowable erosion intensity [15,22–25]. The authors Moore and Wilson [22], Chaplot and Bissonnais [23], Zhang and Wang [15], Liu et al. [24], and Petrikovičová et al. [25] also state that while on short slopes, the water carries away only particles released by water droplets with a small volume drain, while on longer slopes the erosive effect of accumulating water comes to the foreground. When determining the influence of the combination of slope and slope length on the course and intensity of erosion, various forms manifest themselves, which is important not only for the formation of deluvias but also for the development of the entire slope. In general, on straight slopes, the intensity of erosion increases in proportion to the slope length and slope. The direction of the out-flowing water determines the shape of the relief expressed by horizontal and normal (vertical) curvature. The combination of curvatures creates basic forms of relief which are essential for the direction of the out-flowing water and create a precondition for the removal and deposition of material [11,26,27]. Horizontal curvature determines the direction of movement, or outflow of water and material down the slope. It determines whether the material is dispersed or concentrated at a given location. The normal curvature is determined in the fall line in a direction perpendicular to the level line. It determines the movement of material along a slope [28]. The spatial curvature synthesis determines the forms of relief that decisively influence slope processes [29]. Fulajtár and Janský [30] state that the shape of the slope changes the relation between the slope and the slope length. The largest removal is from the convex parts of the slopes, the smaller from the linear and the smallest from concave parts. The development of erosion processes also includes the aspect (exposure of slopes) to the cardinal directions. The research [31–34] shows that on the southern slopes there are soils wasted and degraded by water erosion, while on the northern slopes of the same massifs there are very fertile soils that are fresh with high-production growth. There are differences between the northern and southern slopes, which are also affected by soil moisture [35]. On the southern slopes, there is 2.5 times more soil flushing than on the northern slopes. Accelerated erosion can occur on the southern slopes, especially during the winter breaks.

1.1.2. Secondary Factors

The development of erosion processes was also significantly influenced by changes in land use. Stankoviansky [6] states that significant changes have already taken place in the Neolithic. The resulting effect of the long-term development of human settlements and activities is the creation of a characteristic structure of the agricultural landscape [36]. A mosaic of mostly small narrow fields, oriented along the fall line and the level line, are often situated obliquely to the slope and predominate the landscape [37]. This phenomenon is typical for loess areas in the southern and south-western part of Slovakia. Significant changes occurred after collectivization in the second half of the 20th century. They reflected on the change in the structure of the agricultural landscape. The mosaic of small fields has changed at the expense of large-scale arable land [38]. The soil cultivation system has changed, which contributes to the development of erosion processes [39]. This is also pointed out by the work of Solín and Cebecauer [40] who state that the collectivization process in Slovakia caused about a 40% increase in areas with a high or very high degree of susceptibility to soil erosion. The potential for erosion processes also arose when the type of land use changed. Especially in rugged terrain, deforestation, and the subsequent transformation of the forest into arable land result in the revitalization and acceleration of surface and washout erosion.

Analysis and knowledge of factors that can cause erosion processes is extremely important for the identification of water erosion. Factors enter into the processes of modelling potential soil loss, proposals for anti-erosion measures, optimization of land use, etc.

2. Materials and Methods

2.1. Study Area

The model area is located in the southern part of Hronská pahorkatina hill land (part of Podunajská pahorkatina hill land), mainly in Belianske kopce. It represents a representative north-south transect delimited by the boundaries of the cadastral territories of the municipalities of Belá and Ľubá, with an area of 1808 ha (Figure 1).

Figure 1. Delimitation of the study area within the Slovak republic, aerial view of the configuration of agricultural land mosaic and division into basic hypsometric degrees (Adapted from [https://zbgis.skgeodesy.sk/mkzbgis/sk/teren, accessed on 18 June 2021], with permission from The Geodesy, Cartography and Cadastre Authority of the Slovak Republic, 2021)).

Geomorphologically, the area consists mainly of Belianske kopce, the southeastern part of Hronská tabul'a, the southwestern Strekovské terasy and the southern Búčské terasy [41], which are part of Hronská pahorkatina hill land. Based on the articulation of the relief, according to [41], it represents the relief of lowland hills and high river terraces. Subtypes of accumulation-erosion relief have been identified in the area. From the point of view of the morphological-morphometric type of relief, Tremboš and Minár [42] classify the area as having slightly to moderately rugged hills. The area is characterized by vertical differentiation of soils (a height fragmentation less than 200 m). It is manifested by the occurrence of Luvisols, which predominate over the Chernozems. In the area, there are groups of initial soils (Haplic Regosol), mollisol (Haplic Chernozem, Luvic Chernozem and Haplic Chernozem-eroded, Molic Fluvisol-carbonate) and illimerized soils (Cutanic Luvisol and Cutanic Luvisol-eroded). Based on grain size, these are clayey (medium-heavy) and clay-loam (heavy) deep soils [43].

2.2. *Evaluation of Erosion Factors*

The evaluation of factors and manifestations of water erosion included analyzes of the identified areas threatened by water erosion and individual factors. The relation was determined by partial synthesis of real erosion areas and selected relief properties, which are considered crucial for the development of water erosion (slope, aspect, relief shape, slope length, and combined slope length and slope-factor LS) and types of land use changes.

2.2.1. Areas Threatened by Water Erosion

These areas were identified based on the spatial spread of water erosion in aerial photographs. Erosion detection was performed based on the colour of the surface. The principle of identification is based on tracking the colour differences. Heavily eroded soil has a washed-away A and B horizon and exposed pale loess subsoil. Heavily eroded soils are shown as light spots of oval or rugged amoebic shapes surrounded by darker areas of non-eroded and accumulated soil [30,44,45]. Such erosion detection can be used in the conditions of Central Europe only in the case of loess lowland hills. The spatial spread of water erosion was realized visually based on aerial photographs from six time periods (years 1949, 1970, 2006, 2011, 2014, and 2018). Different time periods partially eliminated the effect of vegetation cover (seasonally partially overlapping the visual manifestation of erosion). The general evaluation of the quantitative representation of erosive surfaces was performed by vectorization of light formations in the images. Areas where erosion has occurred in the past and is still present there or have occurred only in the past or only at present have been selected. They entered the next evaluation as areas threatened by water erosion. Vectorization in the GIS environment created a reference layer, above which spatial units for the next evaluation process were created by the overlay method [11,46]. Subsequently, the verification of erosion processes was carried out using the Edelman soil probe with the possibility of drilling up to 500 cm with a diameter of 50 mm. In 51 drilled soil probes, the thickness of the humus horizon, the presence of soil horizons, the depth of ploughing, the type of the soil-forming substrate and the thickness of the accumulated material were determined there [47].

2.2.2. Selected Properties of the Relief

We focused on the basic morphological properties of relief (slope, aspect, slope length), their combination (shapes of relief, LS factor) and types of land use changes. Based on [11] research to date, we consider them crucial.

Slope is a basic morphometric indicator of the relief. It was evaluated in five categories of slopes: 1 (0–1°), 2 (1–3°) 3 (3–7°), 4 (7–12°), 5 (12° and more), which are based on the slopes categories according to Ilavská et al. [48]. Due to the fragmentation of the territory, the category 0–3° was divided into categories 0–1°; 1–3°.

Aspect affects hydrothermal conditions, sunny exposures, and deteriorating soil properties such as humus content, structure, and soil permeability [21,32,33], leading to soil erosion. In the model area, aspect was assessed in the following categories: levels (−1), N, E, S, W exposition.

The shape of the relief is expressed by the horizontal and vertical curvature of the relief [26,27]. The synthesis of horizontal and normal curvature of the relief was used to obtain the basic shapes of the relief, which can be considered decisive in determining the proportion of material susceptible by erosion., while the combinations express the direction of material movement: XX (convex/convex)—accelerated dispersive motion, XO (convex/linear)—accelerated disperse, XA (convex/concave)—accelerated concentrated, OX (linear/convex)—direct current dispersion, OO (linear/linear)—uniform steady, OA (linear/concave)—DC concentrated, AX (concave/convex)—slow dispersed, AO (concave/linear), DC concentrated, AA (concave/concave)—slow concentrated.

The slope length expresses the influence of uninterrupted slope length per the size of the soil sluice and slope. It was divided into six categories: 1 (0–10 m), 2 (10–30 m), 3 (30–60 m), 4 (60–100 m), 5 (100–200 m), 6 (>200 m).

LS factor (combination of slope length and slope) represents the ratio of soil loss per unit slope area to soil loss per unit plot. The calculation of the topographic LS factor was performed in the GRASS GIS environment (r.watershed module). It was divided into eight categories [49]: 1 (0–0.1), 2 (0.1–0.5), 3 (0.5–1), 4 (1–2), 5 (2–3), 6 (3–5), 7 (5–10), 8 (10 or more).

The analysis of factors was carried out in the environment of geographic information systems based on a digital relief model DMR3.5, adjusted to a resolution of 10 m © ÚGKK SR.

2.2.3. Types of Land Use Change

Land use was assessed over three time periods (1841, 1949, and 2018) [46]. The map of the second military mapping of Austria–Hungary from 1841 and aerial photographs from 1949 and 2018 were used. By vectorization of spatial data in the GIS environment, reference maps with spatial units were created, which were entered into further evaluations. Eleven groups of the elements of land use were created, which were modified according to the methodology of identification of the elements of the secondary landscape structure [50,51]. Changes in land use were assessed between 1841 and 1949, and between 1949 and 2018. These changes were understood as processes that indicate the emergence, extinction, or preservation of a group of land use elements. The process expressed the type of land use change (adapted according to [52]), which took place in the area: intensification, conservation, and extensification. Subsequently, the intensity of the change type was evaluated. During intensification and extensification, strong, moderate, and weak intensities of the type of change were evaluated. The next step was to determine the impact of the intensity of the type of land use change on the spatial expansion of areas with the manifestation of soil erosion. Strong, moderate, and weak intensification with erosion and without erosion, preservation with erosion and without erosion, and weak and moderate extensification with erosion and without erosion were identified [46].

2.2.4. Significance of the Erosion Factors

STAN [53] in the R environment [54] using the brms package [55] was used to model the relation between individual environmental factors (slope, aspect, relief shape, slope length, LS factor, land use changes), categories, and the binary erosion (presence/absence) variable. Testing the influence of selected relief properties and the intensity of the type of land use change on the development of erosion processes, a logistic regression with a Bernoulli distribution and a logit link was used. Due to the sample size (25,672 observations), non-informative priors were used. For better convergence of the models, 4 separate chains of 2000 iterations each were used.

The R random Forest package [56] was used to determine the significance of the individual factors. To avoid overfitting and improve the quality of results, the original dataset was divided into a training (70%) and a test (30%) sample, for evaluation, with 500 trees used for classification. All parameters were tested and selected based on the lowest error rate of the classification. The importance of variables was determined based on the mean decrease of the model prediction accuracy, provided by including the variable in the model.

3. Results

3.1. Identification of the Spatial Distribution of Water Erosion

By identifying the spatial extent of water erosion, areas threatened by water erosion were obtained. These areas represent a total of 408.44 ha (27.78%) of the total area. These areas were entered into a quantitative assessment of the manifestations of water erosion. The areas threatened by water erosion were verified by soil probes. The verification indicates that the predominant soil types are Regosol, Haplic Luvisol (eroded), and Haplic Chernozem (eroded), which indicate the presence of erosion. The presence of erosion is also indicated by alluviums in the lower parts of the slopes. Of the total number of probes, eroded soil was detected in 39 probes (76.4%) (Figure 2).

3.2. Evaluation of Factors

3.2.1. Slope

The combination of threatened areas and slope show the areas where the slope significantly affects or does not affect the distribution of erosion (Figure 3). The effect of steepness was already manifested on slopes with 1–3°, where, after a long-term rainfall, rill erosion was formed on arable land. The most erosive areas can be found in the category 3–7° (54.46%). The areas are used as arable land on which cereals, Siberian kale (*Brassica napus* L.), but also grain maize (*Zea mays* L.), and sunflower (*Helianthus annuus*) are grown. The least erosive areas are in the category of 12° and more (1.20%). However, the highest rate of erosion areas in relation to the area of the category (265.67 ha) is in the slope of 7–12 °, where up to 31.24% of areas are eroded (82.99 ha).

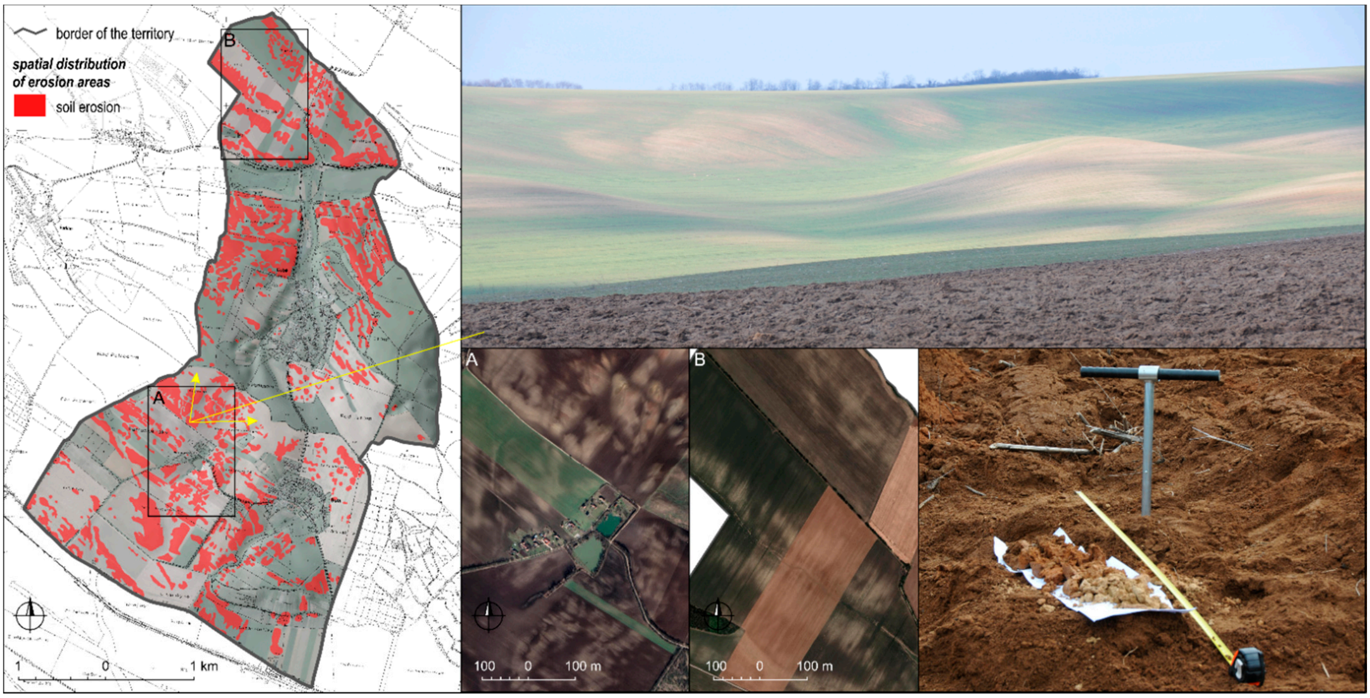

Figure 2. The color contrast is created by the loss of the dark humus horizon, which reveals the light yellow loess. The occurrence of these areas on aerial photos map is shown in (**A**) and (**B**). The figure on the left represents the digitized layer of these erosive areas. The bright (bleached) erosive areas have been verified by soil probes (the figure at the bottom right). By verification it was confirmed that all bleached areas are eroded.

3.2.2. Aspect

The combination of real erosion areas and aspect was the area of the most erosion areas identified on the slopes with southern exposure (32.77%) and the least on the slopes with eastern exposure (16.84%). The highest rate of erosion areas (471.24 ha) is at W exposures, where up to 24.35% of areas are eroded (Figure 3). In the monitored area, the W and S oriented slopes are subject to erosion, which are the ones that are exposed for the longest to sunlight during the day. Soils dry out and soil aggregates break down into dust particles, which are more easily carried away by rainwater. The slopes are mainly used for growing vineyards, which have a greater ability to eliminate erosion processes than arable land. This is represented on the north-facing slopes. The locations are intensively used for agriculture, which gives room for erosion.

3.2.3. Relief Shapes

The evaluation of the relief shape was based on vertical and horizontal curvature. The obtained shapes were combined with real erosion areas. The largest erosion areas in the OO category are of straight, linear shapes (42.78%) (Figure 3). The category was the most common in modelling, but it does not reflect the relation to erosion processes. Other factors play a role there too. The dependence of the relief shape and the erosion areas was manifested in category XX, where up to 32.86% of the areas showed erosion. It is clear from the evaluation that where the convex shape is represented, erosion areas occur to a greater extent (XO, XA, OX, AX).

3.2.4. Slope Length

The effect of the slope length is reflected in the intensity of erosion. It is true that the intensity of erosion increases with increasing slope length, which expresses the horizontal distance from the point of origin of the surface drain, to the point where the slope decreases to such an extent that material is deposited or concentrated in the drain path. By combining real erosion areas and the slope length, areas were identified where the slope length affects or does not affect the development of erosion processes. The largest share of areas threatened by erosion were recorded at the slope lengths of 100–200 m (30.85%) and of 200 m and more (33.54%) (Figure 3).

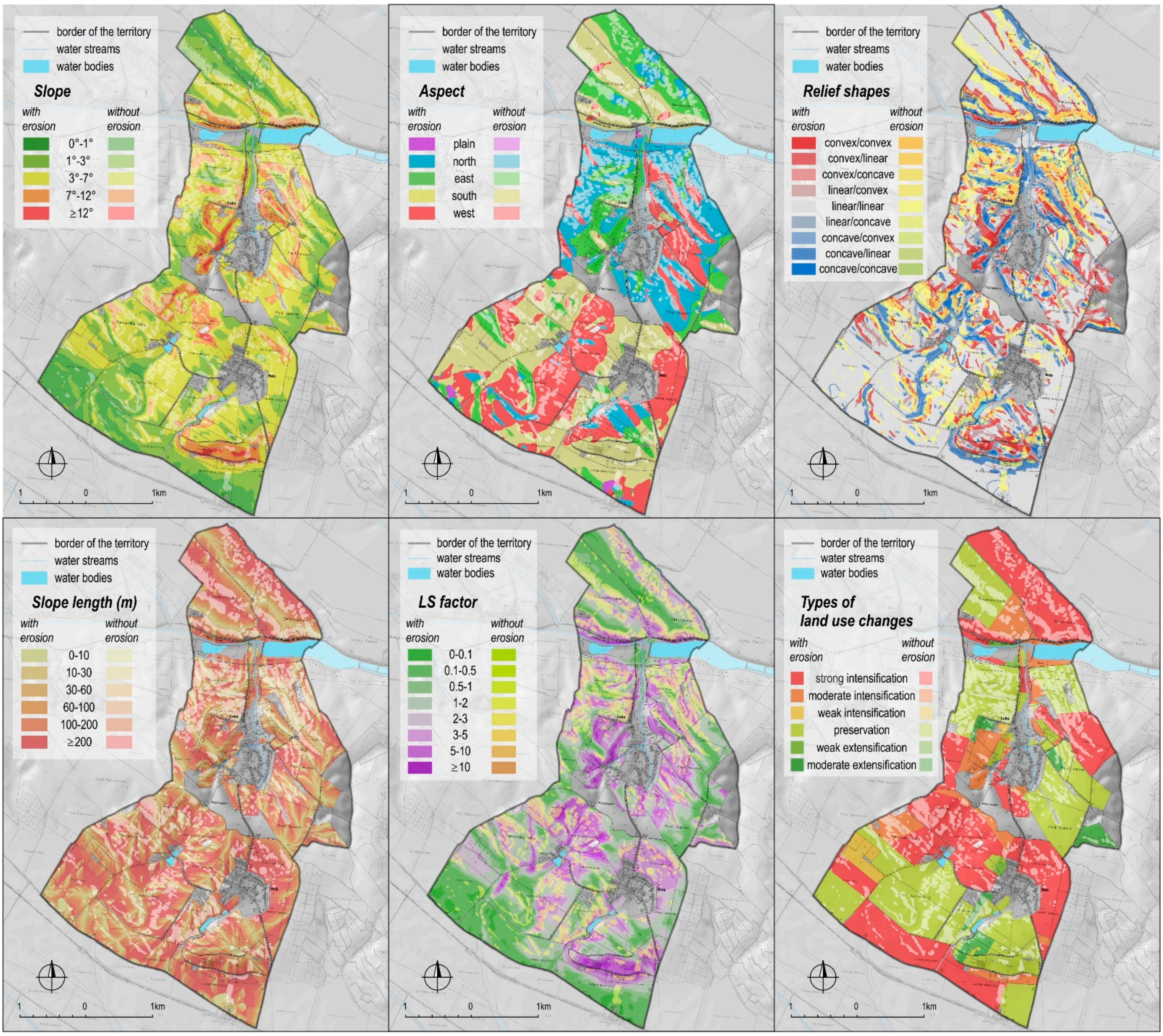

Figure 3. The combination of the spatial distribution of erosion areas and environmental factors. The individual figures show the categories of environmental factors with erosion (left column of the legend) and without erosion (right column of the legend).

3.2.5. LS Factor

The effect of slope and slope length on erosion intensity is expressed by a combination of factor S for the slope and factor L for the slope length (topographic factor). It is determined to find the representative paths of surface drain that characterize the drain conditions of the area. The combination of threatened areas and slope identified the areas where factor LS significantly affects or does not affect the spread of erosion. The evaluation of factor LS shows that the highest proportion of erosion areas is in categories 5 (29.33%) and 6 (29.26%), i.e., the presence of erosion areas increases with increasing value of factor LS, but at extreme positions with the highest the value of factor LS (10 and more) reduces the proportion of erosion areas (16.75%) (Figure 3), because in the model area some of these areas are used differently than arable land.

3.2.6. Types of Land Use Changes

The impact of the intensity of land use change on erosion processes was determined by a combination of identified types of changes and erosion areas. The long-term manifestation of water erosion has manifested itself in the long run mainly on arable land. Area manifestations of soil erosion were identified in the process of extensification (16.26%). The reason is that in the past the soil was severely degraded by erosion (the humus horizon was removed) and bright erosion areas are currently mappable in the field despite a positive extensification change (arable land—permanent grassland). The process of intensification was significant (weak—1.81%, moderate—20.38%, strong—26.03%) (Figure 3). Strong intensification took place mostly on agricultural land. They appear to be the most threatened by water erosion. Erosion also occurred in these areas in 1949. However, the areas had smaller acreage than at present. The change in ownership after 1949 and 1965 has the largest share in this. In 1949, the first unified farmers' cooperative was founded. There was a gradual consolidation of land. Later in 1965, a more significant process of collectivization took place. The area began to be used more intensively. The emergence of large-area fields and the removal of linear landscape elements resulted in an increase in uninterrupted slopes affected by surface erosion. As a result of land use changes related to the collectivization of agriculture, the nature of action and the effectiveness of erosion processes are changing significantly. In addition to the anthropogenic activity, natural factors such as significantly undulating periglacial relief with a relatively high slope of the area with a representation of quality soils, which had the potential to be used for agricultural activity, condition the emergence of erosion processes in the area.

3.3. Significance of Evaluated Erosion Factors in the Development of Water Erosion

The aim was to identify the significance of individual factors in relation to the development of water erosion of the soil. The probability of erosion in individual categories of factors expressed in % was determined there. At the same time, the relation between the individual factors and their significance in the development of erosion was determined.

By testing the slope factor, it was found that the probability of erosion increases with the slope value. The lowest probability is in category 1 and the highest in category 4, which represents a probability higher than 40% (Figure 4). From another increasing value of the slope, the probability of erosion surfaces decreased to the level of 30%. This phenomenon can be explained by the fact that in extreme positions (slope of 12° and more) there is no arable land. The areas are usually forested.

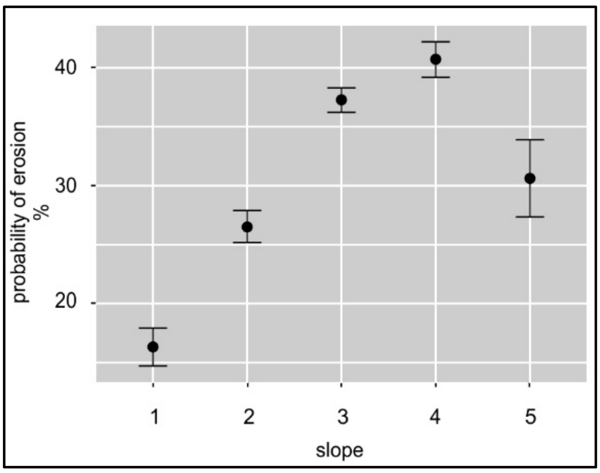

Figure 4. Category of slope: 1 (0–1°), 2 (1–3°), 3 (3–7°), 4 (7–12°), 5 (>12°).

There were no statistically significant differences in the aspect factor. Category 1 was significantly different, representing planes where the level of probability was approximately 10%. N and S exposures reached a value of about 30–35% and in terms of the presence of erosion they appear to be similar. A higher probability was recorded on W-oriented slopes (more than 35%). In contrast, less than 30% was recorded on the E-oriented slopes (Figure 5).

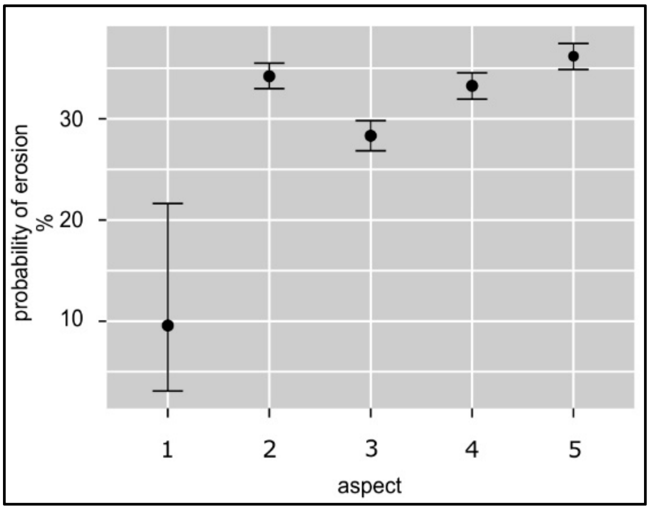

Figure 5. Category of aspect: 1 plane, 2 N, 3 E, 4 S, 5 W.

When testing the probability of the occurrence of erosion surfaces in different relief shapes, a higher presence of erosion in convex parts of the slopes was demonstrated. The highest probability was recorded on convex parts of the slopes. Towards the fallen parts of the slopes, the probability of the occurrence of erosion areas decreased linearly (Figure 6). A higher probability was also recorded in the concave-convex parts, which slow down and at the same time disperse the moving material. This confirms that the vertical curvature and convex shapes are of greater importance.

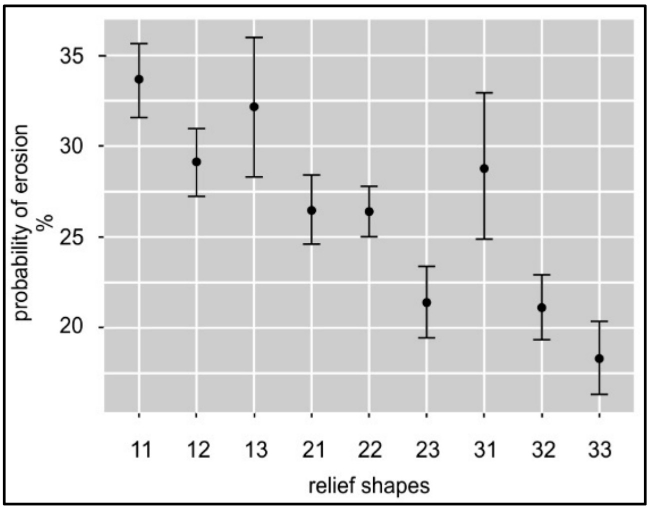

Figure 6. Shapes of the relief category: 11 (convex–convex), 12 (linear–convex), 13 (concave–convex), 21 (convex–linear), 22 (linear–linear), 23 (concave–linear), 31 (convex–concave), 32 (linear–concave), 33 (concave–concave).

The development of erosion areas and the probability of their presence in relation to the lengths of the slopes manifested itself with increasing slope length, while rising sharply in the upper parts of the slopes (Figure 7). The maximum was recorded in the range 30–60 m (upper part of the slopes) at a level of 40–45%. This confirms the correlation with the factor of the relief shapes where, especially in the upper parts of convex shapes, there is the greatest surface development of soil erosion. Subsequently, the probability decreases very slowly, in the last category it increases a little bit. In all categories of slope lengths with a length of more than 60 m, however, the probability reaches a value of about 40%.

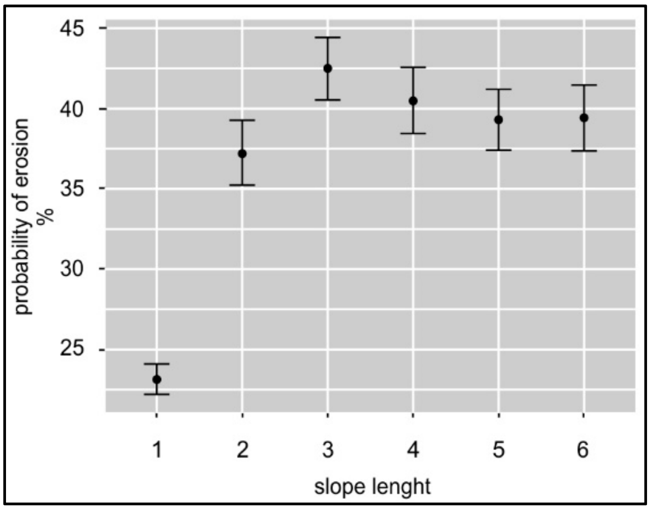

Figure 7. Category of slope length 1 (0–10 m), 2 (10–30 m), 3 (30–60 m), 4 (60–100 m), 5 (100–200 m), 6 (>200 m).

The relation between erosion and factor LS was expected to confirm the hypothesis that the combination of the slope length and slope is a decisive factor in the development of water erosion. Based on testing, the relation between the formation and growth of erosion areas was confirmed with a gradually increasing value of factor LS (Figure 8). The highest value of probability (45%) was recorded in category 5 (value of factor LS 2-3) and continued to decline slowly. In extreme positions at the highest values of the factor (factor LS of 10 and more), the probability begins to decrease. At present, these areas are either mainly located in vineyards on steep southern slopes, or they are grassed.

When detecting the presence of erosion in areas monitoring temporal changes in land use, it was not confirmed that the probability of erosion decreases in the direction of the main categories from intensification through preservation to extensification (Figure 9). This can be explained by the fact that the process of moderate extensification (category 32) represented mainly a change of use from arable land to permanent grassland where erosion areas can still be mapped. A high probability was also recorded in areas where the use of land from the past has been preserved. This phenomenon is related to the fact that the area has been intensively used for agriculture for a long period of time. The predominant part of the area consists of arable land, where erosion has been present for a long time. The declining trend in probability can be observed in the categories of intensification. There, the probability of erosion decreases in the direction of strong, moderate, and weak intensification, while the highest probability was recorded with strong intensification (category 11) at the level of 35%. Category 31 (weak extensification) was represented by a low number of statistically measurable data and did not enter the probability assessment.

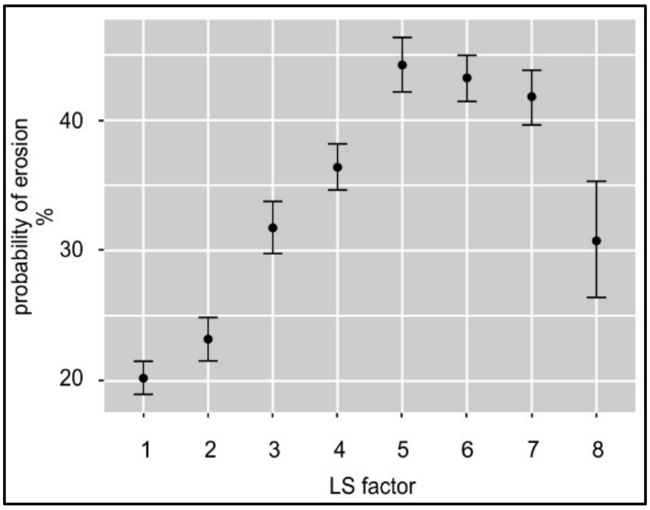

Figure 8. Category of LS factor: 1 (0–0.1), 2 (0.1–0.5), 3 (0.5–1), 4 (1–2), 5 (2–3), 6 (3–5), 7 (5–10), 7 (5–10), 8 (>10).

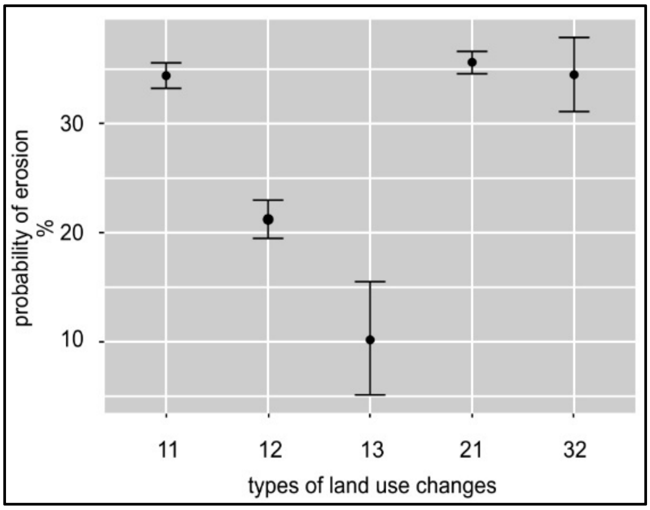

Figure 9. Category of land use change types, 11—strong intensification, 12—moderate intensification, 13—weak intensification, 21—preservation, 32—moderate extensification.

3.4. Estimation of the Significance of the Evaluated Factors

In terms of identifying the significance of individual factors, the mutual relation of factors was subsequently estimated. The aim was to identify the factor with the greatest degree of relation between the factor and the presence of erosive areas. The most important factor appears to be the combination of slope length and slope (Figure 10).

This confirms the assumption that the combination of these variables is crucial in the development of erosion and enters as the main variable in the various tools of erosion modelling. This is indicated by the high value of the significance of the factor of slope. It also enters the determination of factor LS. It follows that factor LS—the combination of the slope length and slope—is an important tool for identifying soil erosion. The following is the land use change factor and the slope length factor, which have been estimated to be similarly significant. Lower significance values were estimated for the relief shape factor and the lowest estimate of significance was for the aspect factor. The error rate of the resulting model was 25.71%.

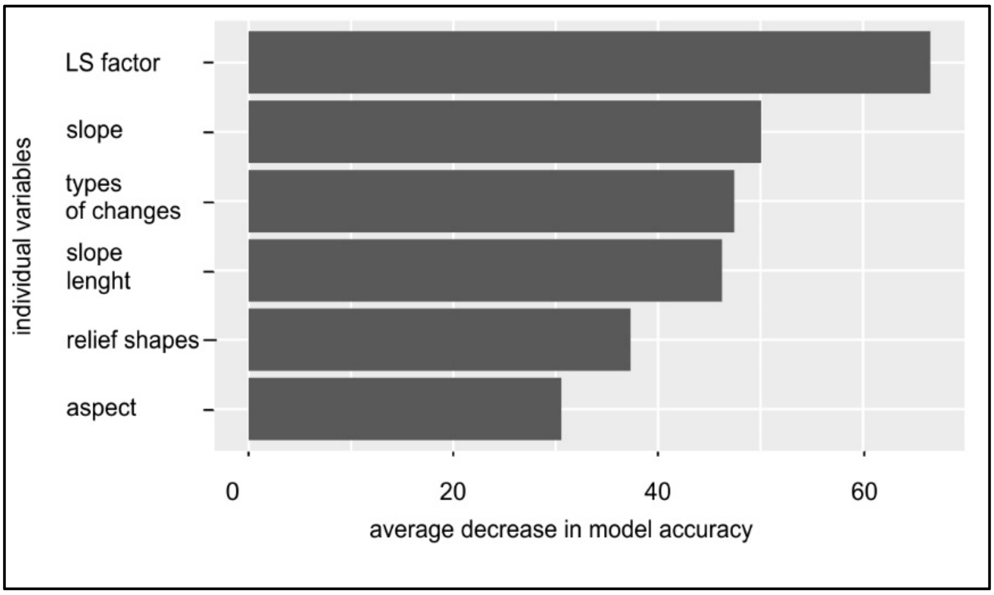

Figure 10. Estimation of the significance of factors.

4. Discussion

The work evaluates the importance of selected environmental factors for the development of water erosion in intensively used agricultural land. In the case of the evaluation of loess lowland hills in Slovakia, there are no complex studies aimed at evaluating individual environmental factors for the development of soil erosion. Individual studies are mainly focused on the evaluation of some factors (mainly slope) without comparing their significance. Selected relief features and land use changes were analyzed. Based on the evaluation, it was confirmed that the slope can be considered as the most important factor conditioning erosion processes. A critical slope of 1° is considered to be critical [11,57]. With such slopes, surface erosion was observed in the area where the values of the critical slope range from 1 to 8° [58]. The slope is important, especially in precipitation erosion, and its importance should not be underestimated even in lower positions with flat relief with the occurrence of less permeable soils [17,34,59]. The authors state that the critical slope limit is given by soil resistance but also by other conditions—slope length, aspect, soil depth, and degree of erosion damage to the soil. For Slovakia, a value of 3° is set for arable land [60,61]. Based on analyses and evaluations, it was found that erosion also occurred in areas with a slope of 1°. It has the highest representation at a slope in the range 7–12°. Tang et al. [62] indicates the average slope. Already at a slope of 4°, considerable erosion damage occurs on the soil, and at a slope of 8°, potholes and ravines form, which cause problems in agricultural land [18,63,64]. Such serious manifestations of erosion did not occur in the model area during the observed period. Rill to groove erosion was monitored there. This is due to the fact that areas with a slope of around 12° are used as vineyards in most areas or forest communities that are situated on them.

The aspect of the slopes is another monitored factor that could contribute to the development of erosion processes [10,65–67]. The authors relate it to the slope. The greater the slope, the more pronounced the erosion. Based on previous research, it is clear that aspect can be considered as a factor entering the process of erosion. The works show that south- and south-facing slopes are more prone to erosion. However, it is not known whether this can be considered as a rule; on the contrary, in many cases aspect appears to be an important but specific factor. In the assessment of aspect, it was confirmed that W exposure of the slopes has the greatest influence on the development of erosion, followed by the S exposure of the slopes. This confirmed the statements of these authors. Morin et al. [33] state that the aspect plays an important role in the development of erosion processes. On the slopes that are exposed to sunlight for the longest time during the day, the soil dries out and then breaks down into finer particles and, when exposed to rainwater, these move to the lower parts of the slope. These statements are also confirmed by Zachar [21,32]. However, he adds that this only applies to desiccating soils. When evaluating the significance of the factors, it was confirmed in the model area that the aspect is the factor that influences the development of erosion the least. This was also confirmed by [31,68], who assesses aspect along with slope and argues that the greater the slope, the more pronounced the effect of aspect on the development of erosion.

Another feature evaluated was the shape of the relief. It has been found that erosion is the most prevalent in localities where convex shapes appear [69]. This is confirmed by Fulajtár and Janský [30] who state that the transport of material from the slope also depends on the shape of the relief because it changes the relation between the slope and the slope length. They state that if the slope is steepest at the top of the slope, the water flowing from the top of the slope uses the greatest slope potential. If the greatest slope is at the bottom of the slope, the greatest slope potential is used by all the water flowing down the slope. On slopes with an uneven steepness, the slope at the bottom plays the most important role there. Therefore, the largest removal is from convex slopes. This is also proved by the results of work prepared for the model area.

In addition to the slope, the slope length also has a significant effect on the course and intensity of erosion. In the model area, it was found that with the increasing slope length, the presence of erosion areas increases. Erosion is most the pronounced at a slope length of 200 m and more, which is the last evaluated category in the area. Gabriels [70], Kinnell [71], Jiang et al. [72] state that on short slopes, the water only carries away particles released by water droplets with a low volume surface drain. On longer slopes, the erosive effect of accumulating water comes to the foreground [73]. It means that on longer slopes a more significant development of erosion processes can be expected, which has also been confirmed. However, the accumulation of deluvates down the slope reduces the erosive effect of water, which may lead to a reduction in erosion even if the slope, which plays an important role in erosion, is not changed. Research does not indicate a value for the critical slope length. This cannot be confirmed even from the research in the model area because other factors enter the development of erosion. The combined influence of the slope and the slope length—factor LS—manifests itself in the course and intensity of soil erosion in various forms [74], which is important not only for the formation of deluvias but also for the development of the entire slope. When evaluating factor LS in the model area, it was found that the presence of erosion is greater and increases with the increasing value of factor LS.

It is clear from the analyses and evaluations of selected properties of the relief that it is not possible to separate them from each other when evaluating erosion processes. This is also mentioned by Fulajtár and Janský [30] who consider them to be the basic parameters of the relief that affect the drain rate. They also think that the shape of the relief is important there. These factors are mutually supportive and influential [15]. The authors [17,59,63] state that slope, as one of the most important factors, affects erosion together with the shape of the relief, aspect, slope length, combined slope length.

These factors can be considered as primary, which are given and constant. However, the occurrence of erosion is also supported by secondary factors that are related to human activity. This was also confirmed by a statistical assessment of the significance of factors that ranked land use just behind the slope. The development of erosion processes is also related to intensive use. Stankoviansky [6], who followed them in the Myjavská pahorkatina hill land, also talks about them. This is also confirmed in research [75,76]. As a result of land use changes related to the collectivization of agriculture, the nature of action and the effectiveness of erosion processes are changing significantly. In the model area, from a long-term perspective, the development of erosion processes affects the whole set of activities that a person performs. Individual groups of elements of land use are changing [37,51,77] and those with lower ecological value are increasing. The main intensification activities are deforestation, development of agricultural activity, changes of land ownership [78], and development of settlements, which were similarly defined by Starkel [79]. Based on the analyses of land use in the model area, the occurrence of surface erosion may be related to deforestation.

Based on the acquired knowledge, it is not possible to clearly determine the factor that would be decisive for the development of erosion. Their assessment should be comprehensive, considering the natural conditions of the area.

5. Conclusions

The results of the evaluation of erosion processes show that water erosion of the soil is an important and simultaneously one of the most serious soil-degradation processes. In solving this problem, it is necessary to focus on its elimination, which is subject to the effective identification of erosion processes and the study of the factors that support its occurrence. The analyses included slope, aspect, relief shape, slope length, LS factor, and types of land use changes. It is clear from the results that the slope has a significant effect on erosion. A significant manifestation of slope was already in the location at a relatively low slope in the range 1–3°. The dependence of the relief shape and the erosive areas manifested mainly in the convex parts. It is clear from the evaluation that where the convex shape of the relief is represented, erosion areas occur to a greater extent. The dependence was less pronounced between aspect and the spread of erosion areas. In the model area, the most eroded areas are on the west and south oriented slopes. The dependence was significantly confirmed at the slope length. It is true that the presence of erosive areas increases with increasing slope length. We recorded the largest share of erosion at a length of 200 m and more. Additionally, with factor LS, the presence of erosive areas increases with the increasing value of factor LS. This factor is essential in all erosion modelling procedures. In the model area, the slope is more significant than this combination, which also appeared to be the second most significant as a self-evaluating factor. We also confirmed the dependence of the type of land use change on the spatial expansion of areas with the manifestation of soil erosion. The intensification of agricultural land is an important condition for the creation and development of erosive areas. The most significant relation of erosion was confirmed in areas of strong intensification.

The results show that the land use management in the territory is inappropriate. In particular, the homogeneous arrangement of agricultural land and the inappropriate inclusion of agricultural crops in the sowing procedure are considered to be inappropriate.

Given the natural conditions of the model area, it would be appropriate to develop a balanced sowing procedure for areas with a slope of up to 7° and to determine the use of the area in location with a slope higher than 7°. Soils that are exposed to erosion should grow crops with a long-term erosive protection effect throughout the vegetation, such as: clover, clover grass mixtures, grasslands, winter crops, garden pea (*Pisum sativum* L.), broad bean (*Faba vulgaris* Moench.), etc. When growing crops included in the sowing procedure, it is necessary to observe the level-line cultivation. On fields with a slope length greater than 100 m, the slope length should be interrupted by crop rotation. In areas with a slope of 7–12°, it is recommended to grow densely sown crops with a predominance of clover grass mixtures, alfalfa, etc. They should avoid growing sparse crops in the upper parts of convex slopes. Areas with a slope higher than 12° should not be used as arable land. The exceptions are perennial forages and grasses. It is appropriate to apply delimitation. In areas with a slope of 12°, delimitation into permanent grasslands is possible. Delimitation to the forest is also permissible in the area where areas with a slope of more than 25° are delimited. There are few such areas in the location and it is necessary to consider the justification of the delimitation of arable land to the forest. From the point of view of soil erosion protection, in areas with the slope of 12°, it is important to ensure at least 40% vegetation coverage of arable land with winter (barley *Hordeum vulgare hybernum*, wheat *Tritcum aestivum* L.), perennial fodder plants (grass and clover mixture), intercrop (bean *Faba vulgaris*, sorghum *Sorghum vulgare*, mustard *Sinapis sp*., pea *Pisum sativum*, lupine

Lupinus sp., buckwheat *Fagopyrum esculentum*, tansy *Phacelia tanacetifolia*, etc.) or leave a stubble-field.

The significance of this work is in the fact that it will help land managers to identify the processes of water erosion, which appear in the lowlands as bright areas. This is also the limit for the identification of erosion areas using remote sensing only for loess hills. In other areas, the validation of the results can be affected by the quality and resolution of the digital terrain model and the differences in the algorithms of the software tools used.

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