Determining Consistency of Tillage Direction with Soil Erosion Protection Requirements as The Element of Decision-Making Process in Planning and Applying Land Consolidation

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Abstract. Water erosion is one of the factors which have negative effect on soil productivity. It often leads to irreversible soil degradation, making soil worthless for agricultural activities. One way of preventing water erosion is making the direction of cultivation perpendicular to the direction of rainwater run-off. Matching the direction with the shape of parcels boundaries in small and extended ones is often possible only through changes in the configuration of property boundaries, which is possible only in the process of land consolidation. The article presents methodology of qualifying the areas for changes in boundaries configuration and cultivation direction in view of existing erosion risk. A computation process was suggested that uses, among others, LIDAR data to model the terrain shape precisely as well as cadastral data that defines the geometry of parcels and, resulting from it, the direction of cultivation and form of use. The suggested process includes also the information on the texture of soil upper horizons from soil agricultural maps. The RUSLE erosion model was applied and the computation process took place in ArcGIS environment with the use of dedicated algorithms suggested and implemented to solve the formulated problem. Computations were conducted for test area of several hundred hectares which was characterized by vast diversity of soil types and landforms. The results prove the usefulness of the suggested method as an element of systems that support decision-making processes used in the stage of determining objects chosen for the realization of consolidating processes (including local consolidation, which covers only chosen fragment of a village). They can also be used in the stage of completing detailed plans of parcels distribution in land consolidation process. The importance of the method is particularly seen in the analysis of areas where land fragmentation indices are unfavourable. Especially in these cases, without the reorganization of boundaries, it is impossible to adapt the direction of cultivation to the requirements of protection against erosion.

1. Introduction
Water erosion is a threat to soil cover on all continents and it is a global problem. In Europe, more than half of the area is vulnerable to the destructive process of water erosion [1]. This results in deterioration of the characteristics that are the base for soil valuation. As a result of water erosion soil loses nutrients, soil particles are eroded and the general state of soil cover worsens. Increasing the velocity of water runoff and reducing the amount of water available for plants are yet another negative instances of water erosion [2]. The damage caused by water erosion is difficult to manage and the costs generated by it are
high and the whole process is generally ineffective. It is also worth to mention that the efforts are time consuming and require expertise.

Effective control of soil erosion requires an ability to predict the amount of soil loss, which would occur under alternate management strategies and practices [3]. Monitoring the areas affected by soil erosion and those which are prone to the occurrence of this phenomenon help to implement, among others, proper soil erosion counter measures. The works should be adapted to the intensity of soil erosion as well as its range. As a consequence, it will help to reduce the costs of soil cover protection. This will directly result in limiting negative impacts in the studied areas as well as will protect potentially endangered nearby fields.

There are several methods that allow to determine the degree of soil erosion. One of the most frequently used methods that measure soil erosion and predict the stage of its development is RULSE (Revised Universal Soil Loss Equation) empirical model. The model was developed by Wischmeier and Smith and allows to estimate the amount of soil material that is eroded throughout the year [4]. This model takes into consideration several determining factors, such as the soil erodibility factor, rainfall intensity factor, slope length and steepness factor, cover and management factor, and support practice factor [5].

Currently, GIS (Geographic Information System) software is used in RULSE (1) development as it may become useful for estimating the amount of eroded material [6]. GIS tools may be used in every stage of RULSE model designing. They also allow to obtain information on spatial distribution of both actual and potential erosion [7]. The amount of material transported by erosion in a year is the final product of the RULSE model [8]:

\[
A = R \cdot K \cdot L \cdot S \cdot C \cdot P
\]

(1)

\(A\) – mean annual soil loss per unit of area \([\text{Mg} \cdot \text{ha}^{-1} \cdot \text{year}^{-1}]\),

\(R\) – rainfall-runoff erosivity factor \([\text{MJ} \cdot \text{ha}^{-1} \cdot \text{cm} \cdot \text{h}^{-1}]\),

\(K\) – soil erodibility factor \([\text{Mg} \cdot \text{ha}^{-1} \cdot (\text{MJ} \cdot \text{ha}^{-1} \cdot \text{cm} \cdot \text{h}^{-1})^{-1}]\),

\(L\) – slope length factor, non-dimensional,

\(S\) – slope steepness factor, non-dimensional,

\(C\) – cover management factor, non-dimensional,

\(P\) – support practice factor, non-dimensional.

The coefficients that directly influence erosion intensity can be divided into natural and anthropogenic. Although the former are difficult to meliorate and the costs generated by it would be unprofitable, the latter can be modified and, thus, lessen soil erosion. Tillage direction relative to landforms is one of the coefficients that can be modified and its value directly relates to the scale of erosion. Proper adjustment of tillage direction to slope reduces the amount of eroded material. Delimiting parcels which require changing tillage direction can be achieved with the use of GIS software.

2. Materials and Methods

The following work contains data representing the area of Szarwark village, located in Dąbrowa Tarnowska Commune, Małopolska Province, Poland (Figure 1). The study area contains 3,260 record parcels, in which the amount of erosion material was calculated. The study used Digital Terrain Model (DTM), Digital Surface Model (DSM) (created with the use of LIDAR technology), soil-agronomic vector map, land-use map, cadastral data, and Maps of Polish Hydrographic Partition (MPHP). The data was then used to calculate the elements of RULSE model. The calculations were completed in ArcGIS software developed by ESRI.
2.1. Combining RULSE model and GIS

The data obtained through Aerial Laser Scanning (ALS) allowed to create terrain model with its land cover as a raster grid file with 0.5 m cell size. Precipitation data, type of soil cover, type of land use, and erosion countermeasures, which were represented by vector format, were then combined with raster data in ArcGIS. GIS software allows to combine the two formats and then conduct analyses with the use of RULSE model [9]. To achieve this, proper ArcGIS modules were applied – Model Builder and HydroTools program overlay.

2.1.1. Rainfall-runoff erosivity factor (R)

This factor represents erosive potential of rainfall and was created with the use of meteorological data (monthly and annual mean precipitation totals) for Szarwark village. Relying on the Fourier index modified by Arnoldus [10], the value of R factor was 66.

2.1.2. Soil Erodibility factor (K)

Using data from soil-agronomic vector map, the K factor was determined. Based on data on granulometric composition, K factor values were ascribed to particular soil bodies [11] (Figure 2a).

2.1.3. Topographic factor -LS

The Slope Length (L) and Steepness Factors (S) constitute Topographic factor (LS factor), which was calculated with the Moore equation [12]. The components (Flow Accumulation, Slope) and the LS factor were calculated in ArcGIS software (Figure 2c).

\[
LS = \left( \frac{\text{Flow Accumulation} \cdot \text{cell size}}{22.13} \right)^{0.4} \cdot \left( \frac{\sin(\text{slope})}{0.0896} \right)^{1.3}
\]  

(2)

Figure 1. The location of study area in Europe, Poland, Malopolska Province, and Dabrowski District

Figure 2. a) Soil erodibility map b) Cover Management map and c) ‘LS’ Factor Map
2.1.4 Cover Management Factor (C)
Cover management factor (C) is a relation of the soil quantity that eroded from the field with specified flora and way of usage to the soil eroded from the model field in black fallow with up and down slope ploughing [13]. Proper values of the C factor were ascribed to every form of land use. [14].

2.1.5 Support practice factor (P)
Support practice factor P determines the relation between soil loss from a plot where the practice (e.g. tillage perpendicular to slope, terracing) is applied and a sample plot. Using GIS tools, the consistency of tillage direction with slope was determined. Revealing the areas where the consistency is or is not present was completed in ArcGIS in two stages. The first required calculating the azimuth for every parcel. Calculate Polygon Main Angle tool was used in this operation. The angle between the North and the parcel axis was ascribed to attribute table and visualized on a vector layer (Figure 3a). The angle was limited to the range of -90° – 90°. From the set of parcels in Szarwark Village, those which are closest to square in shape were isolated. Determining the azimuth for such parcels with the use of Calculate Polygon Main Angel is impossible. Therefore, with the use of cadastral data and orthogonal photographs, such parcels were excluded from the analysis. The next stage consisted of determining mean exposition value for the parcels. The Aspect tool was used to determine the value for the whole area of Szarwark. It was followed by applying Zone Statistics as Table. Like in the first stage, the range was also limited to -90° – 90° (Figure 3b).

The values obtained in the two stages were then combined in one attribute table and the mean exposition value was subtracted from the azimuth value. The results were then classified in respect of the configuration in the relief. If the values were less than 20°, the parcels were classified as having tillage concurrent to the slope. If the values ranged from 80° to 90°, the parcels were classified as having tillage perpendicular to the slope. The remaining parcels were classified as having tillage oblique to the slope. The results were combined in table and then visualized in ArcGIS software (Figure 3c).

3. Results and Discussions
The outcome of the RULSE model with GIS tools designing was a map of erosion risk in Szarwark village. In accordance with the Classification of Erosion Risk [15] the area of Szarwark village was divided into five risk areas (Figure 4).
Spatial distribution of erosion risk zones varies, but lack and very small erosion risk dominate. Higher levels of erosion risk are present in several locations in the village. It is worth to notice that the locations surpass the boundaries of record parcels. A significant number of parcels are characterized by tillage direction parallel to surface runoff, what favours the process of water erosion. A few areas where parcels create large clusters should be distinguished. Here, the only way to reduce water erosion is to change the shapes of parcels’ boundary lines. This will allow to shape tillage perpendicular to slopes.

4. Conclusions
GIS tools allow to delimit areas affected by water erosion. They are universal, what means they can be used to determine erosion level in every given location. GIS tools make it also possible to measure tillage direction and determine its run according to surface runoff. Thanks to the possibility of exposing parcels with unfavourable tillage direction, it is easier to program rural development works (both in the whole village and in some of its parts). This will provide information useful while designing a new configuration of parcels.

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