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A DETERMINATION OF AREA OF POTENTIAL EROSION BY GEOGRAPHIC INFORMATION SYSTEMS

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Abstract. Accelerated water erosion is the major problem of agricultural soils all over the world and also in the Slovak Republic. Accelerated erosion occurs in 55 % of agricultural land. It belongs to physical degradation of fertile land, and the whole process is irreversible. Therefore, it is very important to localize the presence of accelerated erosion and apply the basic principles of soil erosion control. Geographic information systems (GIS) are an effective tool for various environmental analyses, so it can also be succesfully used for determination of potential erosion intensity. The aim of this work was to create a map of domain areas that describes potential water erosion. As an area of interest the cadastral territory of Topolcianky in the Slovak Republic was selected. For this purpose the GIS software Arcview from ESRI was used. Water erosion process was modelled by universal soil loss equation (USLE) which computes an average annual soil loss. The limit values of acceptable intensity of soil loss are defined in the Collection of Laws of the Slovak Republic (Act No 220/2004 Coll). The final result of this work is a map that divides the domain area according to potential annual soil loss into several categories. In this case the domain area was divided into four categories. The first category, named slightly threatened soil, had 620,05 ha of agricultural land (77,48 per cent of the total agricultural land of domain area). The second category, called averagely threatened soil, had 106,56 (13,32 per cent of the total agricultural land). The third category (intensively threatened soil) had 70,91 ha (8,86 per cent of the total agricultural land) and finally the fourth category (very intensively threatened soil) had 2,74 ha (0,34 per cent of the total agricultural land).

Keywords: soil erosion, universal soil loss equation, geographic information systems, digital model of terrain.

1. Introduction

The aim of this work was to create a map of domain areas that describes potential water erosion. That means we tried to localize the presence of potential erosion and estimate its intensity.

Erosion is a process of mechanical detachment of the soil by moving water, wind and other destructive elements (snow, ice, etc). After detachment the soil particles are removed, transported and accumulated [1].

According to [2] soil erosion is a two-phase process consisting of the detachment of individual particles from the soil mass and their transport by erosive agents such as running water and wind. When sufficient energy is no longer available to transport the particles, the third phase, deposition occurs.

The process of erosion includes:

1. Detachment – the separation of soil particles from the soil mass, expressed in units of mass/area.

2. Sediment movement downslope – sediment transport, described as sediment load.

3. Deposition expressed as mass/area – the accumulation of sediment on the soil surface or in the water.

Classification of erosion according to [1] is:

1. Water erosion.
2. Cryogenic erosion.
3. Wind erosion.
4. Biological erosion.
5. Anthropogenic erosion.

The most extended form of water erosion is the stormwater erosion which is divided into several phases. The first phase is the impact of raindrops on the soil surface. The second phase represents the process of soil particle splashing connected with destruction of soil aggregates. The third phase is transport of detached soil particles as an action of surface runoff. The last phase is accumulation of transported soil particles [3].

Impacts of water erosion

The main on-site impact of water erosion is reduction in soil quality that results from the loss of the nutrient-rich upper layers of the soil, and the reduced water-holding capacity of many eroded soils. Erosion removal from the upper horizons of the soil results in a reduction in soil quality, i e a diminution of the soil's suitability for agriculture or other vegetation. This is because eroded upper horizons tend to be the most nutrient-rich. Also, because the finest constituents of eroded soil tends to be transported furthest, eroded soils become preferentially depleted of their finer fraction over time; this often reduces their water-holding capacity. Loss of soil quality is a long-term problem; globally, the most serious impact of soil erosion may well be its threat to a long-term sustainability of agricultural productivity.

In addition to its on-site effects the soil that is detached by accelerated water or wind erosion may be transported considerable distances. This gives rise to 'off-site problems' of soil erosion. Water erosion's main off-site effect is the movement of sediment and agricultural pollutants into watercourses. This can lead to the silting-up of dams, disruption of the ecosystems of lakes and contamination of drinking water. In some cases increased downstream flooding may also occur due to the reduced capacity of eroded soil to absorb water.

Movement of sediment and associated agricultural pollutants into watercourses is the major off-site impact resulting from erosion. This leads to sedimentation in watercourses and dams, disruption of the ecosystems of lakes and contamination of drinking water. Rates of erosion do not have to be high for significant quantities of agricultural pollutants to be transported off-site. This is a shorter-term impact than loss of soil quality; in more affluent areas of the world it can be the main driver for present-day soil conservation policy initiatives. A more minor off-site effect can occur in situations where eroded soil has a decreased capacity to absorb water: increased runoff may lead to downstream flooding and local damage to property.

Natural and accelerated erosion

Natural or geologic erosion has occurred at a relatively slow rate since the Earth was formed. It is a major factor in creating the Earth as we know it today. The great river valleys of the panhandle, the rolling farmlands and orchards of the central ridge, the productive estuaries and the barrier islands of the coast are the products of geologic erosion and sedimentation. Except for some cases of shoreline and stream channel erosion, natural erosion occurs at a very slow and uniform rate and is a vital factor in maintaining environmental balance. Accelerated erosion is the increased rate of erosion caused primarily by the removal of natural vegetation or alteration of the ground contour. Farming and construction are the principal causes of accelerated erosion, although any land-disturbing activity can increase the natural erosion rate.

The object of soil conservation is to ensure that land is only used in such a way that the use can be sustained indefinitely. This will be achieved when the rate of soil loss is no greater than the rate of soil formation. The rate of formation cannot be precisely measured, but in the conditions of the Slovak Republic it will take 200 years to produce 1 cm of topsoil, that means formation rate of 0,7 t/ha/year [4]. The values of soil formation rate according to different authors are listed in Table 1.

Table 1. Values of soil formation rate according to different authors

<table>
<tr><th>Author (source)</th><th>mm/y</th><th>m^3/ha/y</th><th>t/ha/y</th></tr>
<tr><td>BENNETT, H. H.</td><td>0,023–0,116</td><td>0,23–1,16</td><td>0,324–1,62</td></tr>
<tr><td>KOHNKE, H.</td><td rowspan="2">0,011–0,96</td><td rowspan="2">0,11–9,6</td><td rowspan="2">0,157–13,44</td></tr>
<tr><td>BERTRAND, A.</td></tr>
<tr><td>HUDSON, N.</td><td>0,089</td><td>0,89</td><td>1,25</td></tr>
<tr><td>SMITH, R. M.</td><td rowspan="2">0,018–0,11</td><td rowspan="2">0,18–1,1</td><td rowspan="2">0,250–1,480</td></tr>
<tr><td>STAMEY, W. L.</td></tr>
<tr><td>USA</td><td>0,178–0,89</td><td>1,78–8,9</td><td>2,5–12,5</td></tr>
<tr><td>SR</td><td>0,05</td><td>0,5</td><td>0,7</td></tr>
</table>

Naturally acceptable soil loss will depend on current soil condition (fertility, soil depth). The soil erosion in the conditions of the Slovak Republic is acceptable if the predicted intensity of erosion (potential soil loss) is not greater than limit values of erosion intensity. Limit values of acceptable erosion in Slovakia for different soil depths are defined in the Collection of Laws of the Slovak Republic [5] (See Table 2).

Table 2. Limit values of acceptable erosion for different soil depth in Slovakia

Soil depth	Limit values of soil loss
shallow soils (< 0,3 m)	4 t ha^{-1} per year
soils of medium depth (0,3–0,6 m)	10 t ha^{-1} per year
deep soils (0,6–0,9 m)	30 t ha^{-1} per year
very deep soils (> 0,9 m)	40 t ha^{-1} per year

Modelling of soil erosion

Before planning conservation work it is necessary to estimate how fast soil is being eroded through the use of models used in erosion studies. Estimated values of soil loss may be compared with limit values, and effects of conservation strategies can be determined.

Most of the models are based on defining the most important factors and through the use of measurements, experiments and statistical technique, relating them to soil loss. The starting point for the whole modelling must be clear definition of objective, time period of predicting, scale of operation and definition of area which model should operate. Single models could be divided into different types.

Types of models according to [2]

1 Physical models are scaled-down hardware models usually built in the laboratory.
2 Analogue models are based on the use of mechanical or electrical systems analogous to the system under investigation.
3 Digital models are based on the use of digital computers to process vast quantities of data:

a) Physically-based models are based on mathematical equations to describe the processes involved in the model.
b) Stochastic models are based on generating synthetic sequences of data from the statistical characteristics of existing sample data.
c) Empirical models are based on identifying statistically significant relationships between assumed important variables where a reasonable database exist.

Empirical models

- The simplest model is a black box type relating sediment loss to either rainfall or runfall [6].
- Universal Soil Loss Equation [7].
- SLEMSA-The Soil Loss Estimator for Southern Africa [8].
- The Morgan, Morgan and Finney method.

Physically-based models

- CREAMS-Chemical, Runoff and Erosion from Agricultural Management Systems.
- WEPP-Water Erosion Prediction Project-was designed to replace USLE.
- GUESS-Griffith University Erosion Sedimentation System.
- EUROSEM-European Soil Erosion Model.

2. Investigation object and methodology

Study site

As an area of interest the cadastral unit of Topolcianky was selected (Fig 1). Topolcianky village is situated near the town of Nitra in midwestern Slovakia. The cadastral has an elevation from 194,0 m to 566,3 m above the sea level. The biggest part of this locality is covered with oak and hornbeam woods, but the southern sector is deforested and used for agriculture. The soil texture is loam and clay loam of Novak scale. The climate is characteristic of transient central-European one with the highest amount of precipitation during summer storms.

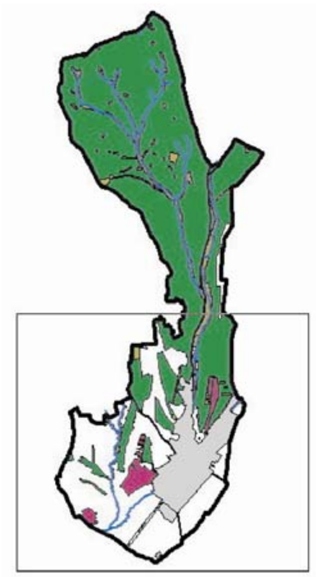

Fig 1. Cadastral unit of Topolcianky

The whole area of agricultural land in the cadastral unit of Topolcianky makes 8 002 468,5 m^2 or 800,25 ha.

The map of actual landscape structure is added in appendices.

Modelling of water erosion

The process of potential water erosion in the cadastral unit of Topolcianky was modelled by the transformed universal soil loss equation [9] which computes average potential annual soil loss as

$$S_{p,pot} = R \cdot K \cdot L \cdot S, \tag{1}$$

where S_p – average annual potential soil loss [t ha^{-1} per year], R – erosivity factor, K – soil erodibility factor, L – slope length factor, S – slope steepness factor.

Erosivity factor R is an index of erosivity in a location. Erosivity reflects the effects of both rainfall amount and rainfall intensity on erosion. An average annual erosivity value can be computed as

$$R = E \cdot i_{30}/100, \tag{2}$$

where R – average annual erosivity [$MJ.ha^{-1}.cm.h^{-1}$], E – kinetic energy of individual storm [$J\ .\ m^{-2}$], i_{30} – max 30 min intensity of rainfall [$cm\ h^{-1}$].

The soil erodibility factor K is a measure of erodibility for the unit plot condition. The unit plot is 22,1 m long on a 9 percent slope, maintained in continuous fallow, tilled up and down hill [10].

$$S_u=R \cdot K=E \cdot i_{30}.K, \tag{3}$$

where S_u – soil loss from the unit plot measured for an individual storm [$t\ ha^{-1}$], $E \cdot i_{30}$ – erosivity of the storm that produced the storm soil loss.

The factors L and S together represent the so-called topographic factor (LS). This is actually a ratio of the soil loss per unit area of a particular plot with soil loss per unit area of a standard plot, 22,13 m long and with 9 % slope. Slope length factor and slope steepness factor can be computed as topographic factor (LS):

$$LS = l_d^{0,5}(0{,}0138 + 0{,}0097\ s + 0{,}00138\ s^2), \tag{4}$$

where l_d – continuous hillslope length (m), s – angle of slope (%).

Computing process in GIS

For creating the Digital Model of Terrain (DMT) of the cadastral unit of Topolcianky and also all the necessary thematic maps, the software Arcview was used (Fig 2). Thematic maps represent the individual components of the USLE (factors R, K, L and S).

Planimetric and hypsometric information was taken from paper map lists to the scale of 1: 10 000. Map lists were scanned and transformed into TIFF format with resolution 5885 x 4521 pixels and georeferenced into the local coordinate system (S-JTSK).

The DMT represents a set of data with assigned location which characterize the geometric properties of a terrain (heigth above the sea level, slope, relief orientation, etc). The DMT was computed in module named "Spatial Analyst" from a grid which contains input points with defined elevation above the sea level through the use of an appropriate interpolation method. In this case the method of regularized spline with tension was used.

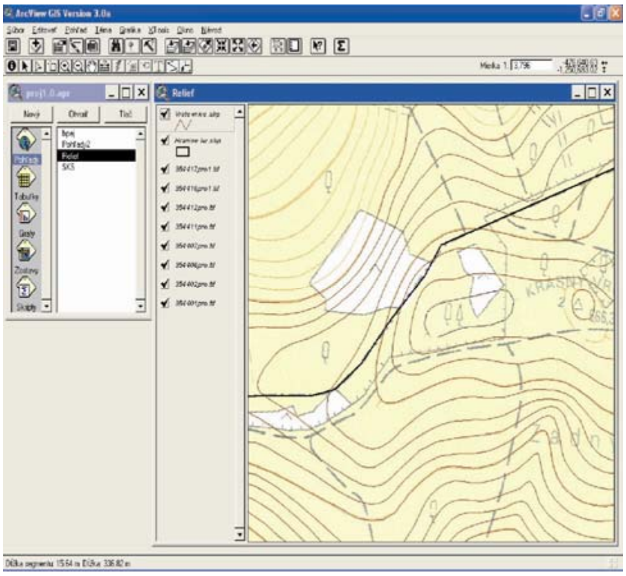

Fig 2. Creating DMT by Arcview

In the next sequence the DMT was used for generating two thematic maps. Gradient of a slope map, expressed in percentage, represents the slope steepness factor (*S*). A hillslope length map in metres represents the soil length factor (*L*). The value of L·S factor was computed through the use of an Arcview tool named "Map calculator". We used equation 4.

Erosivity factor, valid for the area of interest, was determined for a meteorological station in Tesarske Mlynany [11]. Regionalization of the R-factor for the territory of the Slovak Republic was attempted, based on the existing ombrographic records of storm rains obtained at the meteorological stations.

The factor of soil erodibility (K) can be derived from the soil texture, soil organic matter content, soil structure and permeability. A map of soil erodibility, which expresses the soil erodibility factor (K) in the area of interest, was created using the soil properties data from Institute of Soil Science and Conservation Research in Bratislava.

K-factor was related to the units of the basic map, resulting from the Complex Soil Survey, and to the main soil units according to the system of the Valuated Soil Ecological Units (VSEU). The VSEU characteristics are coded in such a way that the first figure of the code denotes the climatic region, the second and third ones denote the main soil unit, and the fourth figure stands for the slope and its orientation.

We have used the VSEU characteristics and information about the areal extent of VSEU, stored in the database of the Integrated Soil Information System for each cadastral territory.

Calculation of potential erosion (Eq 1), using all the thematic maps, was realized with an Arcview tool "Map calculator". The result was a map of potential erosion. (See Fig 3).

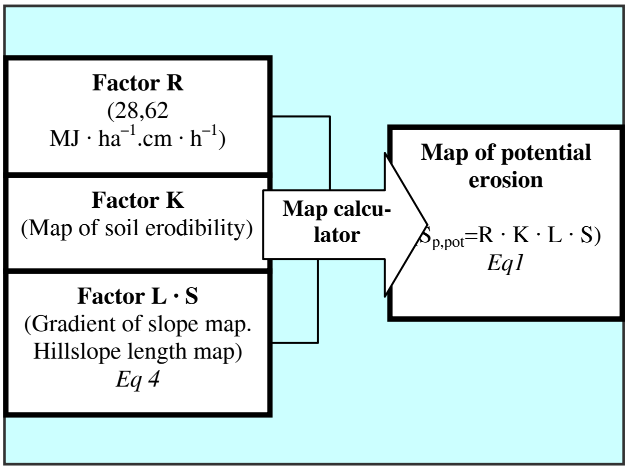

Fig 3. Calculation of potential erosion (Eq 1)

3. Results and discussion

For interpretation of calculated results, we used Potential Erosion Index expressed as

$$Index\ PE = \frac{S_{p,pot}}{S_{p,l}}, \tag{5}$$

where $S_{p,pot}$ – average potential annual soil loss (t ha^{-1} per year), $S_{p,\,l}$ – limit values of soil loss (t ha^{-1} per year).

Table 3. Values of Index PE and degree RPE for different soil categories

Category	slightly threatened soil	averagely threatened soil	intensively threatened soil	very intensively threatened soil
Index PE	<1	1–2	2–7	7–28
Degree RPE	1	2	3	4

Table 4. Division of domain area into categories according to Index PE and degree RPE

Category	slightly threatened soil	averagely threatened soil	intensively threatened soil	very intensively threatened soil	TOTAL
Area of agricultural land (ha)	620,04	106,56	70,91	2,74	800,25
Fraction of total agricultural land (%)	77,48	13,32	8,86	0,34	100

We have computed the values of Potential Erosion Index. The computed interval of Potential Erosion Index was from 0 to 18. According to Index PE, the area of interest was divided into parts with a different precondition for potential erosion. This precondition is defined as degree of potential risk of water erosion (degree RPE) (See Table 3).

The whole area of agricultural land in the cadastral unit of Topolcianky makes 8 002 468,5 m^2 or 800,25 ha.

The first category, called slightly threatened soil, had 620,05 ha of agricultural land (77,48 per cent of the total agricultural land of domain area). An area of 106,56 ha (13,32 per cent of the total agricultural land) was attached to the second category, called average threatened soil. The third category had 70,91 ha (8,86 per cent of the total agricultural land), and the fourth category had 2,74 ha (0,34 per cent of agricultural land).

For a more transparent view of the results, see Table 4, Fig 4 and the Map of Potential Erosion (added in appendices).

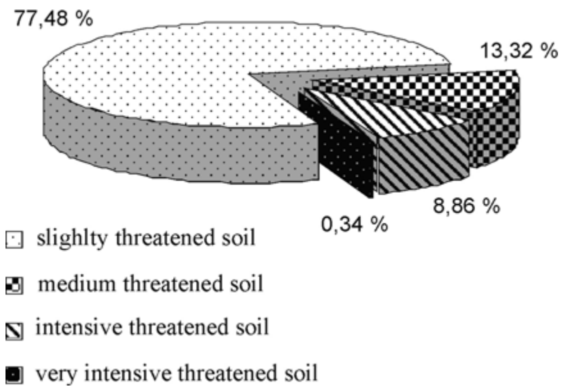

Fig 4. Abundance of potential risk of water erosion degree in cadastral unit of Topolcianky

For a more detailed evaluation of the computed results, the cadastral territory can be divided into several parts according to the Map of Potential Erosion (added in appendices). We have divided the domain area into the west and east parts. It is an effective separation for the purpose of evaluation of potential erosion according to natural conditions.

The values of slope length in the east side of domain area are relatively high, but computed values of slope steepness are minimal. Therefore, the calculated values of Potential Erosion Index are mostly smaller than 1. That means the biggest area of the east part of the cadastral territory was attached to the first category of potential risk of water erosion (slightly threatened soil).

In contrast, the values of slope steepness in the west part of the cadastral territory are fundamentally higher, therefore, the values of Potential Erosion Index are maximal here (7–18).

The east part of domain area contains a slightly threatened soil, so it is not necessary to apply any erosion control practices.

The risk of potential erosion in the west part of the cadastral territory is relatively high, therefore, it is necessary to apply at least the basic erosion control principles.

3.1. Strategies for erosion control in the cadastral territory of Topolcianky

From the definition of the soil erosion process (in Introduction), it follows that the strategies for soil conservation must be based on: covering the soil to protect it from raindrop impact; increasing the infiltration capacity of the soil to reduce the runoff; improving the aggregate stability of the soil; and increasing surface roughness to reduce the velocity of runoff.

The general principles of erosion control according to [4], aimed at reducing its intensity include:

1. protection of the soil surface against the effect of the kinetic energy of rain drops, runoff and wind;
2. increase of the infiltration capacity of the soil to reduce the volume and velocity of runoff;
3. improvement of the aggregate stability of the soil to increase the soil erodibility;
4. increase of surface roughness to reduce the velocity of runoff and wind;
5. increase of the retention and accumulation capacity of the soil surface to reduce the volume and velocity of runoff;
6. control of runoff from sloping land to reduce the rill and gully formation and safely dispose of excess water.

According to Slovak Technical Standard No 75 45 01 „Conservation of agricultural soils. Basic regulations“, erosion-control measures are divided into the following four types:

1. anti-erosion land organization, mainly including:
   - distribution and location of woodland, grassland and cropland;
   - shape, size and position of fields;
   - grazing land management;
   - communication network.
2. anti-erosion agricultural practices, mainly including:
   - contour cultivation;
   - mulching;
   - crop rotation;
   - tied ridging.
3. biological measures, mainly including:
   - strip cropping;
   - conservation grassing;
   - conservation afforestation.
4. technical (mechanical) measures, mainly including:
   - terrain regulation;
   - terracing;
   - waterways.

Anti-erosion agricultural practices and biological measures are the basic proposals concerning erosion-control measures for the cadastral territory of Topolcianky. In the specific field conditions of domain area we can recommend a conservation system based on:

1. contour tillage (or agrotechnics);
2. permanent plant cover with preservation effect;
3. cover (secondary) crop combined with zero-tillage technology, strip cropping.

1. Contour tillage conservation effect is based mainly on contour ploughing with earth turning against

slope and crop drilling along contours. This is reflected in surface runoff minimalization in wintertime till vegetation starts. During this period infiltration capacity is increased up to 50 %.

2. Rotation of crops with conservation effect is based on the principle of permanent plant cover. The most suitable crops are grasses, perennial forage crops and winter crops. Mulching cover crops in combination zero tillage technologies offer most effective soil surface protection. Its duration is since August till the end of May.

3. Contour strip cropping will reduce soil losses even further. Strip cropping, ideally, involves alternating strips of forage and a row crop on the contour. In situations when forage is not grown, cereal crops are a reasonable substitute to be alternated with corn.

4. Conclusions

The whole area of the study site was divided into four categories according to its precondition for potential erosion (the values of potential rates of erosion, computed through the USLE in GIS).

The first category, called slightly threatened soil, had 620,05 ha of agricultural land (77,48 per cent of the total agricultural land of domain area). An area of 106,56 ha (13,32 per cent of the total agricultural land) was attached to the second category, called averagely threatened soil. The third category had 70,91 ha (8,86 per cent of the total agricultural land), and the fourth category had 2,74 ha (0,34 per cent of agricultural land).

For a more detailed evaluation of the computed results, the cadastral territory can be divided into several parts according to the Map of Potential Erosion (added in appendices). We have divided the domain area into the west and east parts. The east part of domain area contains a slightly threatened soil, so it is not necessary to apply any erosion control practices there. The risk of potential erosion in the west part of the cadastral unit is relatively high, therefore, in this part it is necessary to apply at least the basic erosion control principles.

Localization of soil erosion is a relatively difficult problem. Direct observations and measurements of water erosion intensity are not yet performed regularly and systematically in the Slovak Republic. The above-mentioned technique can be used for evaluation of the soil erosion process in the country.

Acknowledgements

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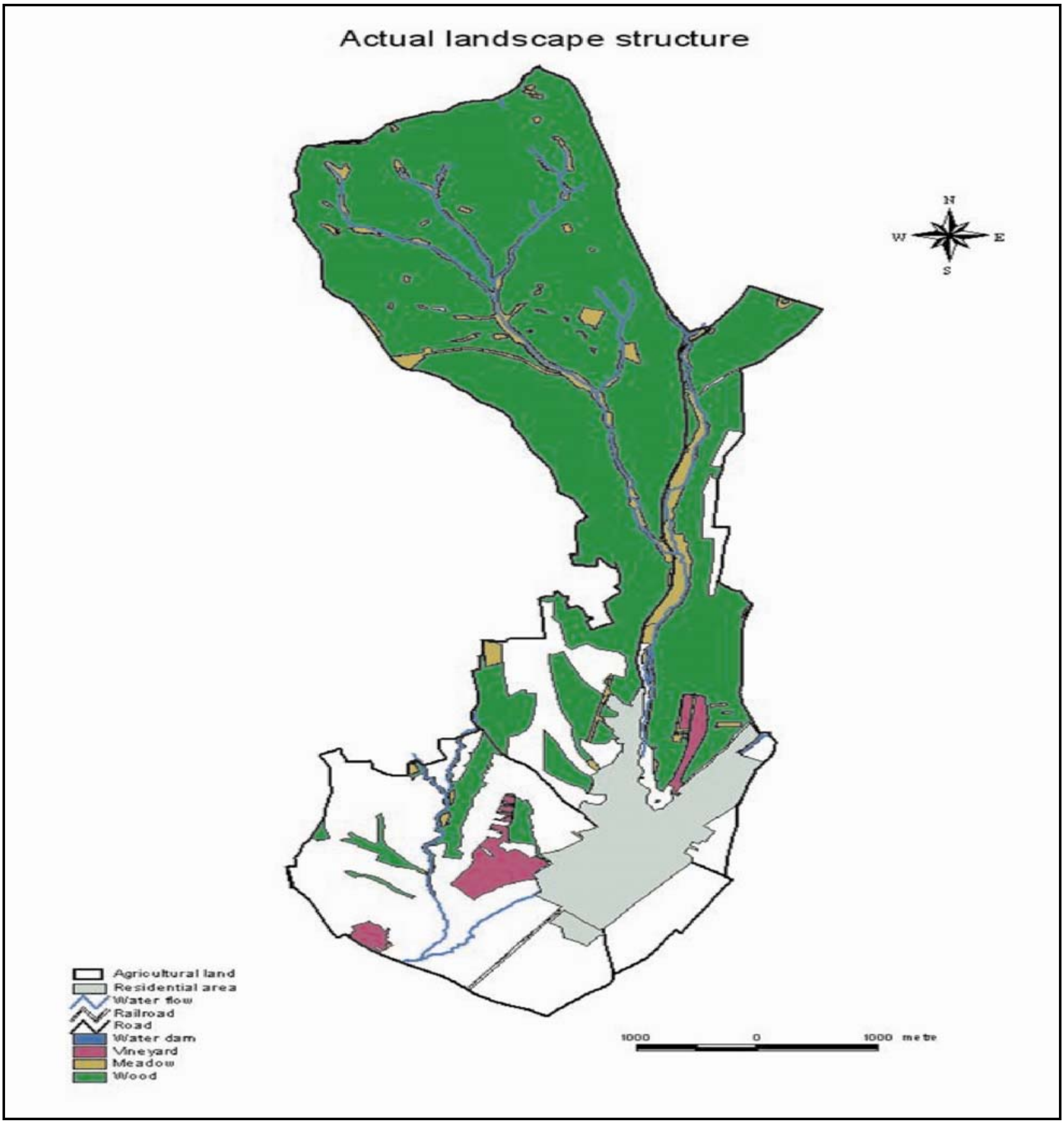
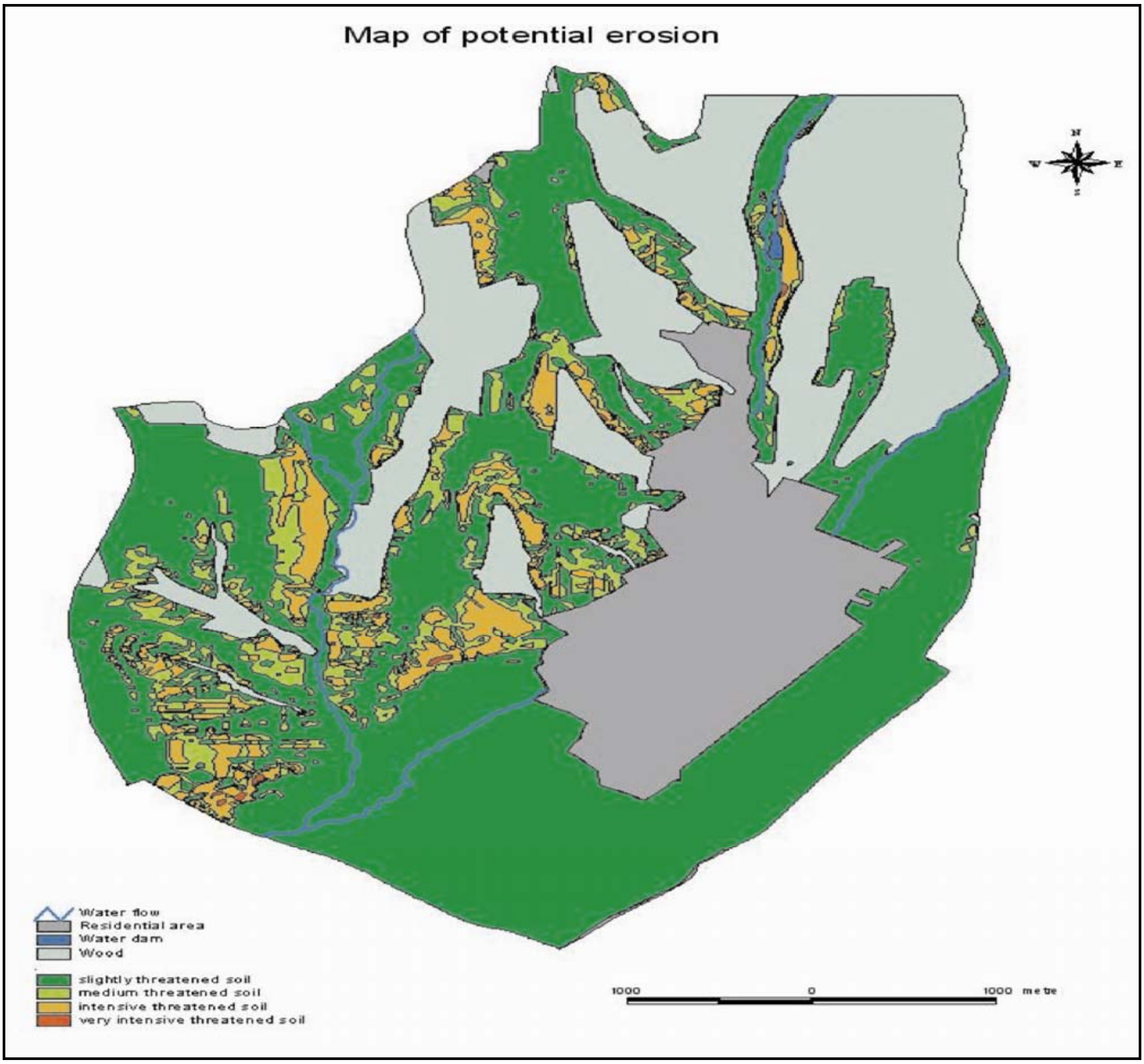
Appendix 1. Map of Actual Lanscape Structure of Study Site (Cadastral unit of Topolcianky)



Appendix 2. Map of Potential Erosion



POTENCIALIOS EROZIJOS TERITORIJŲ NUSTATYMAS GEOGRAFINĖMIS INFORMACINĖMIS SISTEMOMIS

P. Šurda, I. Šimonides, J. Antal

Santrauka

Sparti vandens sukeliama erozija yra pagrindinė žemės ūkio problema visame pasaulyje, kartu ir Slovakijos Respublikoje. Sparti erozija vyksta 55 % žemės ūkio naudmenų. Tai lemia derlingų žemių fizinė degradacija, ir šis procesas yra negrįžtamas. Todėl yra labai svarbu nustatyti vietas, kuriose vyksta sparti erozija, ir taikyti erozijos kontrolės principus. Geografinės informacinės sistemos (GIS) yra efektyvi priemonė įvairioms aplinkosauginėms analizėms atlikti, ir jos gali būti sėkmingai pritaikytos ir galimos erozijos intensyvumui nustatyti.
Šio darbo tikslas buvo sukurti žemėlapį, kuriame būtų nurodytos potencialios vandens sukeliamos erozijos sritys. Tyrimui parinkta kadastrinė Topolciankų teritorija Slovakijos Respublikoje. Šiam tikslui buvo naudota *ESRI* firmos GIS programinė įranga *Arcview*. Vandens sukeltos erozijos procesas buvo modeliuotas taikant bendrąją dirvožemio praradimo formulę (*Universal soil loss equation*, *USLE*), kuria apskaičiuojamas vidutinis kasmetinis dirvožemio praradimas. Ribinė priimtina dirvožemio praradimo intensyvumo vertė yra apibrėžta Slovakijos Respublikos įstatymų. Baigiamasis šio darbo rezultatas yra žemėlapis, kuris dalija teritoriją pagal potencialų kasmetinį dirvožemio praradimą į kelias kategorijas. Šiuo atveju teritorija buvo padalyta į keturias kategorijas. Pirmajai kategorijai, pavadintai mažai grėsminga, buvo priskirta 620,04 ha žemės ūkio naudmenų (77,48 % visų nagrinėjamos teritorijos žemės ūkio naudmenų). Antrajai kategorijai, pavadintai vidutiniškai grėsminga, buvo priskirta 106,56 ha (13,32 % visų žemės ūkio naudmenų). Trečiajai kategorijai (grėsminga) buvo priskirta 70,91 ha (8,86 % visų žemės ūkio naudmenų). Ketvirtajai kategorijai (labai grėsminga) buvo priskirta 2,74 ha (0,34 % visų žemės ūkio naudmenų).

Reikšminiai žodžiai: dirvožemio erozija, bendroji dirvožemio praradimo formulė, geografinės informacinės sistemos, skaitmeninis vietovės modelis.

ОПРЕДЕЛЕНИЕ ОБЛАСТЕЙ ПОТЕНЦИАЛЬНОЙ ЭРОЗИИ ПОЧВЫ С ПОМОЩЬЮ ГЕОГРАФИЧЕСКИХ ИНФОРМАЦИОННЫХ СИСТЕМ

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Резюме

Интенсивная эрозия почвы в результате вымывания водой является одной из основных проблем сельского хозяйства в мире, а также в Словацкой Республике. Интенсивной эрозии в республике подвергается 55 % сельскохозяйственных угодий. Происходит физическая деградация плодородных земель, причем процесс этот необратим. Поэтому важно установить место интенсивной эрозии и применить основные принципы контроля за эрозией почв. Географические информационные системы (ГИС) являются эффективным средством для проведения различных природоохранных анализов, в том числе и для определения интенсивности возможной эрозии почв.
Целью настоящей работы было создать карту, на которой были бы указаны области потенциальной эрозии, вызываемой водой. Для исследований была выбрана кадастровая территория Топольсянки в Словацкой Республике. Использовалось программное устройство Arcview фирмы ESRI. Процесс эрозии, вызываемый водой, моделировался с применением общей формулы потерь почв (USLE), благодаря которой подсчитывалось среднее количество ежегодно утрачиваемых почв. Приемлемое предельное значение интенсивности потерь почв установлено законом Словацкой Республики (Act No 220/2004 Coll.). В результате выполненной работы была создана карта, на которой территория в зависимости от ежегодно потенциально теряемых почв была разделена на четыре категории. К первой категории, так называемой слабой опасности, отнесено 620,04 га сельскохозяйственных почв (77,48 % всех сельскохозяйственных почв на исследуемой территории). Ко второй категории (средней опасности) отнесено 106,56 га (13,32 % всех сельскохозяйственных почв). К третьей категории (интенсивной опасности) отнесено 70,91 га (8,86 % всех сельскохозяйственных почв). К четвертой категории (особенно интенсивной опасности) отнесено 2,74 га (0,34 % всех сельскохозяйственных почв).

Ключевые слова: эрозия почвы, общая формула потери почвы, географические информационные системы, числовая модель местности.

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