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SOIL EROSION RISK ASSESSMENTS USING GIS TECHNOLOGIES – BULGARIAN EXPERIENCE

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Abstract

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Soil erosion is widely recognized environmental problem. Geographic information systems (GIS) integrate hardware, software, data, procedures and trained personnel for capturing, managing, analyzing, and displaying all forms of geographically referenced information. The report presents briefly two GIS for soil erosion risk assessments, which were developed for use by decision makers for sustainable management of soil resources to evaluate, analyze and predict soil erosion risk and localize the need for application of measures to control soil erosion by rain and wind. These systems integrate models, adapted and evaluated for the conditions in Bulgaria and available information at scales of M 1: 400 000, M 1: 200 000 and M 1: 100 000 about digital elevation, rainfalls, winds, air temperature, soil cover and permanent land cover. The GIS for water erosion risk assessments integrates the USLE approach and the GIS for wind erosion – the WEQ approach. The models were adapted in order to use available data from routine large-scale soil survey and published climatic observations in Bulgaria as input parameters. Presented results demonstrate some of the advantages and the disadvantages of the GIS technologies for soil erosion risk assessments, which have influenced directly and indirectly the development of the GIS technologies.

Key words: erosion, rainfall erosivity, soil erodibility, Bulgaria
Abbreviations: GIS – Geographic information systems; USLE – Universal Soil Loss Equation; WEQ – Wind Erosion Equation

Introduction

Soil erosion is widely recognized global environmental problem. Assessments of average annual soil losses range from 0.0045 to 0.45 t. ha^{-1} depending on the slope degree at natural conditions (Young, 1969) and from 45 to 450 t. ha^{-1} – in arable lands (Morgan, 1995). The World map of anthropogenic land degradation recognizes the water erosion of soils as the most considerable degradation, representing 53 % of the total soil degradation (Oldeman et al., 1991).

Geographic information systems (GIS) integrate hardware, software, data, procedures and trained personnel for capturing, manipulating, storing, analyzing, managing and displaying all forms of geographically referenced information. Since 1970-ies, when the first GIS were developed in Canada, they have been used increasingly in many areas of the human life for specific studies, including resource management, regional and territorial planning, and cartography.

Geographic information systems have multiple applications for assessment and analyses of soil erosion factors and risk. They enable: (1) localization of territories, which require special attention and need of additional research and application of measures to control erosion; (2) development of policy for protecting soil from erosion; (3) modeling the impact of climate change on soil and vegetation resources; (4) modeling and predicting the reduction of the available volume of natural and artificial lakes due to siltation caused by intensive soil erosion processes in their catchments; (5)

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modeling the potential of the water resources and the surface runoff; (6) defining the territories for water protection and (7) assessments of the desertification risk.

This report presents the experience of a joint team from the Soil Erosion Department at the Institute of Soil Science, Agrotechnology and Plant Protection "Nikola Poushkarov" and the Executive Soil Resources Agency in using the GIS methodology for assessments of the soil erosion factors and risk.

Materials and Methods

Sheet water erosion of soil

GIS for assessments of sheet water erosion was developed (Lazarov et al., 2002; Nikolov et al., 2007) based on adapted for Bulgarian conditions models for assessment of the soil erosion factors and the soil loss and the available small- and medium-scale data (M 1: 400 000, M 1: 100 000) for slope gradient, intensive rainfalls, soil cover and permanent land cover. The soil erosion risk assessments are based on one of the most widely used models for average annual soil loss predictions (Wischmeier and Smith, 1965, 1978), widely known as the Universal Soil Loss Equation (USLE):

$$A = R\ K\ LS\ C\ P \quad (1),$$

where: A is the predicted average annual soil loss, t. ha^{-1}, R is the rainfall erosivity factor, MJ. Mm. ha^{-1}. h^{-1}, K is the soil erodibility factor, t. ha. h MJ^{-1}. ha^{-1}. mm^{-1}, LS is the topography factor, C is the crop and management factor, P is the factor of erosion control practices.

The rainfall erosivity

It was evaluated by the *factor R* (EI_{30}), adapted for Bulgaria by a model, which was parameterized and validated using data for rainfall characteristics from 9 sites for long-term soil erosion studies (Rousseva, 2002b). Values for R were then calculated for 84 meteorological stations with long-term observations with published data (Kyuchukova et al., 1986) on the annual and monthly number and frequency of intensive rainfalls with duration T ≥ 30 min and the amount of a single intensive rainfall with the same duration.

The soil erodibility

It was assessed by the *factor K*, calculated by the nomograph of Wischmeier et al. (1971).

$$K_e = 1.77\ 10^{-6}\ M^{1.14}\ (12 - a) + \\ + 0.043\ (b - 2) + 0.033\ (4 - c) \quad (2)$$

The formula 2 was adapted to the available data in Bulgaria using transformation of soil texture data and pedotransfer functions for assessing the soil profile permeability (Rousseva, 1997, 2001, 2002b). The nomograph was then validated using data from long-term field plot soil erosion studies for 17 soils (Rousseva, 2002a). Soil erodibility of each one of the soil mapping units defined by the updated digitalized soil map for Bulgaria at a scale M 1:400 000 was characterized by mean value and its standard deviation, calculated from routine data of soil particle-size distribution, humus content and soil structure determined by the large-scale soil surveys M 1:10 000 and M 1:25 000, characterizing all polygons of distribution of the respective soil unit. Data from a total number of 1925 soil profiles were collected, summarized and used to characterize the soil erodibility of all 77 soil mapping units, i.e. about 1.7 soil profiles per 100 km^2.

The topography factor LS

It combines the influence of the gradient (s, %) and length (λ, m) of the slope on the soil loss from erosion. The latest modification of the system (Nikolov et al., 2007) uses the formula of Moore et al. (1993) for assessing the LS factor and thus it combines the influences of the slope gradient (θ°- teta) and the specific area (A_s, m^2/m) contributing to generation of the surface runoff on the soil loss from erosion:

$$LS=1.4*(As / 22.13)^{0.4} * (\sin \theta°) / 0.0896)^{1.3} \quad (3)$$

This formula has an advantage compared to the original formulas of Wischmeier & Smith (1978), as it results in more precise soil loss assessments for 3D environment due to the replacement of the slope length with the specific area contributing to generation of the surface runoff.

The assessment of the potential soil erosion risk

It is based on the distributions of the country's territory according to the degrees of rainfall erosivity, soil erodibility and topography.

The assessment of the actual soil erosion risk

It is based on the distribution of the country's territory according to the degrees of potential soil erosion risk, soil loss tolerance (T) of arable and non-arable soils and the crop and management factor C. Assessments of the C factor are based on a deterministic approach using average annual data for the monthly distributions of the canopy cover of the main field crops for each one of the agro-ecological regions and the rainfall erosivity factor for the 84 meteorological stations.

Wind erosion of soil

GIS for wind erosion risk assessment was developed (Dzhodzhov et al., 2005) based on adapted for Bulgarian conditions models for assessments of wind erosion factors and rates as well as available small- and medium-scale (M 1: 400 000, M 1: 100 000) information about the slope gradient, climate parameters (wind, precipitations and air temperature), soil cover and permanent land cover. The wind erosion risk assessments are based on adapted for Bulgarian conditions model for predicting the average annual soil loss from deflation. The model is developed in the USA for the purposes of the soil conservation planning (Woodruff and Siddoway, 1965; Skidmore et al., 1970; Hagen et al., 1971; Lal, 1994) and it is known as the Wind Erosion Equation (WEQ):

$$A = 0.0015*2.718^{-V/4500} *(L^{1.87} * K^2 * (C/100)^{1.3} *L^{0.3}) \text{ for } IKCL < 5.5*10^6 \quad (4)$$

$$A = 2.718^{-V/4500} * (I*K*C/100) \text{ for } IKCL \geq 5.5*10^6, \quad (5)$$

where: A – average annual soil loss from deflation, t. ha^{-1}. $year^{-1}$, I – factor of soil susceptibility to deflation, t. ha^{-1}. $year^{-1}$, K – factor of surface roughness, C – climate factor, L – mean unprotected field length, m, V – factor of the crop protection effect, kg. ha^{-1}.

Climate influence

It is assessed by the average annual values of the *climate factor C* for meteorological stations with published long-term climate data for precipitations, air temperature and velocity of dominant winds (Malinov et al., 2005). Mean monthly values of the soil moisture in the surface layer, needed for the C factor assessments, were calculated as a function of the precipitation rates and the air temperature.

Soil susceptibility to deflation

Its assessment is based on transformed (Rousseva, 1997) soil texture data used for calculating *I factor* values. Each one of the soil mapping units defined by the updated digitalized soil map for Bulgaria at a scale M 1: 400 000 was characterized by mean value and its standard deviation of the I factor, calculated from routine data of soil particle-size distribution, humus content and soil structure determined by the large-scale soil surveys M 1:10 000 and M 1:25 000, characterizing all polygons of distribution of the respective soil unit.

Wind erosion risk

Its assessments are based on average annual predicted soil loss using formulas (4) and (5). The *influence of vegetation* is assessed by the *factor of surface roughness* (K), calculated using data for the row height and the distance between the rows for 15 most widely distributed field crops with high deflation risk and *the factor of the crop protection effect (V)* – defined on the basis of average annual crop yields calculated from long-term statistical data for the main field crops over the administrative regions in Bulgaria. *The mean unprotected field length* (L) is categorized in accordance with the slope gradient.

Results

Sheet water erosion of soil

The values of the rainfall erosivity factor were categorized in 8 classes: 0–50, 51–100, 101–200, 201–400, 401–600, 601–800, 801–1000, 1001–1500, 1501–2000 and > 2000 MJ mm ha^{-1} h^{-1} and mapped in ArcView 9. It was found that $EI_{30} > 400$ for and area exceeding 60% of the country's territory, including $400 < EI_{30} \leq 600$ for 29 %, $600 < EI_{30} \leq 800$ for 20 % and $EI_{30} > 1000$ MJ mm ha^{-1} h^{-1} for 12%.

The values of the soil erodibility factor were categorized then in 6 classes: $0 < K \leq 0.01$, $0.01 < K \leq 0.02$, $0.02 < K \leq 0.03$, $0.03 < K \leq 0.04$, $0.04 < K \leq 0.05$ and > 0.05 t ha h ha^{-1} MJ^{-1} mm^{-1}. The soil erodibility map for Bulgaria, based on the soil maps for Bulgaria at scales M 1: 400 000 and M 1: 25 000 and ArcView 9 shows that K > 0.03 for an area exceeding 62 %, $0.03 < K \leq 0.04$ for 54%, $0.04 < K \leq 0.05$ for 3.3 % and K > 0.05 t ha h ha^{-1} MJ^{-1} cm^{-1} for 4 % of the country's territory.

The factor LS is categorized in 6 groups: $0 < LS \leq 1$, $1 < LS \leq 2$, $2 < LS \leq 4$, $4 < LS \leq 6$, $6 < LS \leq 8$, LS > 8, and mapped using digital elevation model 50 m and ArcView 9.

Potential average annual soil loss values calculated in accordance with Equation (1) with C = 1 and P = 1 have been categorized in 7 groups: 0–5, 6–10, 11–20, 21–40, 41–100, 101–200, > 200 t ha^{-1} y^{-1} and mapped using the map of catchments for Bulgaria and ArcView 9. It was found that about 62 % of the country's territory has a potential erosion risk exceeding 10 t ha^{-1} y^{-1}, while the potential erosion risk exceeds 40 t ha^{-1} y^{-1} for 43 % of the country's territory.

The actual soil erosion risk is categorized in 6 groups: < T, T–5, 6–10, 11–20, 21–40, > 40 t ha^{-1} y^{-1} and mapped using the permanent land cover obtained by CORINE (2002), the map of the agro-ecological regions and ArcView 9. The actual soil erosion risk exceeds 5 t ha^{-1} y^{-1} for 1/4 of the arable land, including 24 % of the cropland and 65 % of the vineyards and orchards.

Wind erosion of soil

Obtained values for 99 meteorological stations are categorized in 8 classes: 0–0.5, 0.6–1.0, 1.1–2.5, 2.6–5.0, 5.1–10.0, 10.1–30.0, 30.1–60.0 and > 60.0 and mapped using ArcView 9. Over 50% of the country's territory is characterized with a value of the climate factor exceeding 5.

The I factor values were categorized in 5 groups: 0–125, 126–150, 151–200, 201–275 and > 275 t ha^{-1} $y^{-1}$and mapped using the soil maps for Bulgaria at scales 1: 400 000 and 1: 25 000, and ArcView 9. The soils for 85% of the territory of Bulgaria have susceptibility to deflation exceeding 150 t ha^{-1} y^{-1}.

Calculated soil loss was then categorized in 8 groups: 0–0.5, 0.6–1.0, 1.1–2.5, 2.6–5.0, 5.1–10.0, 10.1–30.0, 30.1–60.0 and > 60.0 t ha^{-1} y^{-1} and mapped using ArcView 9. Analyses of the data show that 19.7% of the cropland area is characterized by deflation risk from 2 to 10 t ha^{-1} y^{-1}, 1.4% – 10–20 t ha^{-1} y^{-1}, 11.7% – 20–50 t ha^{-1} $y^{-1}$and 2.7% over 50 t ha^{-1} y^{-1}.

Conclusions

Presented results demonstrate some of the advantages and the disadvantages of the GIS technologies for soil erosion risk assessments, which have influenced directly and indirectly the development of the GIS technologies so far. Advantages are related to lower cost, faster elaboration and higher flexibility of the final product – easier change of the scales and the projections, revision of the maps according to the consumers' needs as well as reproduction of digital data for a larger group of users. The main disadvantages are associated with the necessity of higher capital investments at the beginning as well as some trends to production of not indispensible maps or maps of pure quality. Necessity of continuous improvement of the models for assessment of the soil erosion factors and rates, which are integrated with the GIS, should not be underestimated.

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