# The determination of the areas at risk of soil degradation by water erosion

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Abstract: Water erosion (except from intra-soil and raindrop erosion) occurs only upon the formation of rainfall surface runoff and a puddle creation on the soil surface. Both of these phenomena are observed when the intensity of rainfall, resp. melting snow is greater than the intensity of infiltration. Moreover, the formation of puddle erosion is dependent on the zero soil surface slope gradient. Surface runoff from the investigated slope (catchment) begins when the depth of the design rainfall exceeds the initial retention of the soil surface on slope, resp. in the catchment. By the application of Soil Conservation Service curve number method the depth of initial potential retention of the study area can be calculated. This calculation uses the representative value for the study area (or its part), which is, in the case of the design rainfall, a function of the soil hydrological properties, the quality of soil cover and land-use. The aim of the contribution is to present a simple approach of initial determination of potential surface retention at the catchment scale (Tajná Stream catchment, West Slovakia). The analysis shows that whole agricultural as well as forest land in the study area is potentially prone to water erosion. The advantage of the proposed approach is that inputs for this method are generally available for the whole Slovakia (and probably for the other countries too) as well as the fact that it can be successfully implemented into the GIS interface.

Keywords: water erosion, surface retention, intensity of design rainfall, surface runoff, CN value

## Introduction

Soil erosion is recognized as one of the most common physical soil degradation processes in Slovakia. Although being one of the processes naturally occurring in the environment, when the soil erosion intensity evidently exceeds the intensity of soil formation, various social, economic, environmental and agricultural problems emerge. Particularly, water erosion that threatens more than 55% of agricultural soils in Slovakia needs to be taken into consideration when managing and planning human activities by application of erosion control principles (e.g. land consolidation, soil fund organization, landscape planning, integrated catchment management) (Kondrlová, Antal, 2015). For the purposes of information processing, analysis and decision making geographical information systems are widely used nowadays (Kondrlová, 2009). Water erosion (except from intra-soil and raindrop erosion) occurs only upon the formation of rainfall surface runoff and a puddle creation on the soil surface. Both of these phenomena are observed when the intensity of rainfall, resp. melting snow – $i_R$ is greater than the intensity of infiltration – $v_i$ (at the saturation related to saturated hydraulic conductivity of the near-surface soil). Moreover, the formation of puddle erosion is dependent on the zero soil surface slope gradient. To determine the depth of the surface runoff ($H_{S,R}$), water balance method can be used as the simplest option at the slope as well as catchment scale (Antal, Igaz, 2008):

$$H_{S,R} = H_P - H_I - H_A - V_i \qquad\qquad (1)$$

where:   $H_{S,R}$ - depth of surface runoff (mm)
$H_P$ - depth of precipitation (mm)
$H_I$ - depth of rainfall interception by the soil surface vegetation cover (mm)
$H_A$ - depth of rainfall accumulated on the soil surface (mm)
$V_i$ - depth of water that will infiltrate into the soil during rainfall duration (mm)

Water balance model is often used also for modelling purposes (e.g. van Dijk, 2010). Since it is difficult to estimate the soil infiltration rate for different landuse types at varying quality of land cover, we recommend to apply the worldwide known Soil Conservation Service curve number (CN) method (Chow, 1964) that is used e.g. in catchment scale calculations of sediment delivery ratio and the amount of direct surface runoff (Šinka, Kaletová, 2013; Šinka, 2009). This approach estimates the potential (maximum) retention (2) and the depth of direct runoff while it takes into account specific soil hydrological properties, the quality of soil cover and landuse. This procedure finds its application also at width design of vegetation filter strips (Antal, 1985; Soulis, Valiantzas, 2012; Ishtiyaq, Vivek, Mukesh Kumar, 2015):

$$A = 25.4 \left[(1000/CN)-10\right] \tag{2}$$

where:  $A$ - potential surface retention (mm)
$CN$ - representative CN value for specific landuse category

$$D \geq L_n * H_{O,L} / (0.2 * A - H_p) \tag{3}$$

where:  $D$ - width of the vegetation filter strip (m)
$L_p$ - the length of the adjacent slope (m)
$H_{O,L}$ - amount of surface runoff from the upslope area (mm)
$A$ - potential surface retention of the filter strip (mm)
$H_p$ - the amount of design rainfall (mm)

To gain a mathematical solution, the expression $(0.2 * A - H_p)$ has to be greater than 0. After employing the formula (2) the initial potential surface retention of the study area can be calculated as follows (Antal, 1985):

$$H_{R,i}=(5080/CN_i-50.8) \tag{4}$$

where:  $H_{R,i}$ - depth of potential surface retention (mm)
$CN_i$ - representative CN value for specific landuse category

The aim of the contribution is to present a simple approach of initial determination of potential surface retention at the catchment scale using the GIS interface.

## Materials and methods

The Tajná Stream catchment (647 ha) is located in the northern part of the Nitra region in the Danubian Upland, in western Slovakia. Tajná Stream (4.7 km) flows into Širočina River in the cadastral area of the Tajná municipality (48°15'42.6" lat., 18°21'42.58" long.). The climate varies from warm to temperate with either Atlantic or continental influence. The average annual air temperature is 10° C and average annual rainfall is 590 mm (Kondrlová, 2009). The catchment is used predominately for forestry (51 %) and agricultural production (Table 1) on Cambisols and Luvisols, respectively.

*Table 1: Representation of the landuse categories in the Tajná Stream catchment*

| Category | Area, ha | % | Category | Area, ha | % |
|---|---|---|---|---|---|
| forest | 332.30 | 50.81 | shrubs | 10.14 | 1.55 |
| arable land | 271.19 | 41.46 | built-up area | 5.93 | 0.91 |
| orchard | 10.12 | 1.55 | garden | 4.90 | 0.75 |
| pasture | 9.19 | 1.40 | roads | 3.50 | 0.53 |
| meadow | 5.03 | 0.77 | water | 0.34 | 0.05 |
| vineyard | 1.13 | 0.17 | quarry | 0.29 | 0.04 |

All the digital analyses and map outputs were processed in ArcGIS 10.2.2 (© ESRI) using various processing tools, mainly the Spatial Analyst and Conversion Tools. Landuse map was created after digitizing the topographic maps (at scale 1:25000). The information on soil types was obtained from seven-digit code of soil-ecological units (© Soil and Soil Protection Research Institute, Bratislava), that were processed as a result of Complex Soil Survey in 1961 – 1970 in Slovakia. The information on forest soils was obtained from the National Forest Centre in Zvolen.

## Results and discussion

To convert the soil map into hydrological soil groups (HSG) tables available in Slovak literature were used (Antal, Igaz, 2008; Šinka, Muchová, Konc, 2013). The soils of the hydrological soil group B, C, D were identified around the catchment. The same literature sources were used for assigning CN values (adjusted to Slovak conditions) on individual forest land (forests, shrubs) and agricultural land (arable land, meadow, pasture, orchard, and vineyard) categories occurring on represented HSGs (Table 2). In case that such a source missing, the original methodology of Chow (1964) can be used. CN values closer to 100 interpret a low potential of surface retention and a high potential of surface runoff or puddle formation. The risk of puddle formation was limited to areas with the slope gradient less than 1°. According to our analysis the puddles are more likely to form on the ridges as well as valleys - where very flat areas naturally occur. The potential surface retention in the study area was estimated according to the formula (4). Forests showed to be the most stable landscape feature regarding the water erosion control, with the potential surface retention reaching up to 42 mm of water depth (Figure 1). Due to combination of soils with low infiltration potential (group D) and weak vegetation cover (predominantly patchy shrubby areas) the lowest retention potential was identified on pastures and shrubby areas (down to 5.6 mm).

Table 2: Recommended CN values according to hydrological soil group (HSG), landuse management and the quality of vegetation cover (Hrádek, 1989* ; Šinka, Muchová, Konc, 2013[+])

| HSG | Landuse categories | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- |
| | Arable land* | Pasture* | Meadow* | Shrubs* | Forest* | Orchard[+] | Vineyard[+] |
| | CN values | | | | | | |
| B | 75 | 80 | 60 | 80 | 55 | 73 | n.a. |
| C | 80 | 85 | n.a. | 90 | 65 | 82 | 82 |
| D | 85 | 90 | 80 | 90 | n.a. | 86 | n.a. |

n.a. - no applicable for current study area

Taking into account the rainfall depth at specific return period (10-years, periodicity = 0.1 and 50-years, periodicity=0.02) obtained from the closest meteorological station in Vráble (Antal, Igaz, 2008) it was possible to estimate the depth of the water layer that would be created on the soil surface at the specific surface retention capacity (Figure 2 and Figure 3).

Localities with the risk of surface runoff or puddle formation were identified on areas where the depth of the design rainfall – $H_{D,R}$ exceeded the initial retention of the soil surface on slope, resp. in the catchment – $H_{R,i}$. In general whole study area is threatened by water erosion at some extent - in the forest land water layer of 12 mm of depth (at $H_{D,R}$ = 53.8 mm), respectively 24 mm (at $H_{D,R}$ =65.9 mm) would be potentially formed.
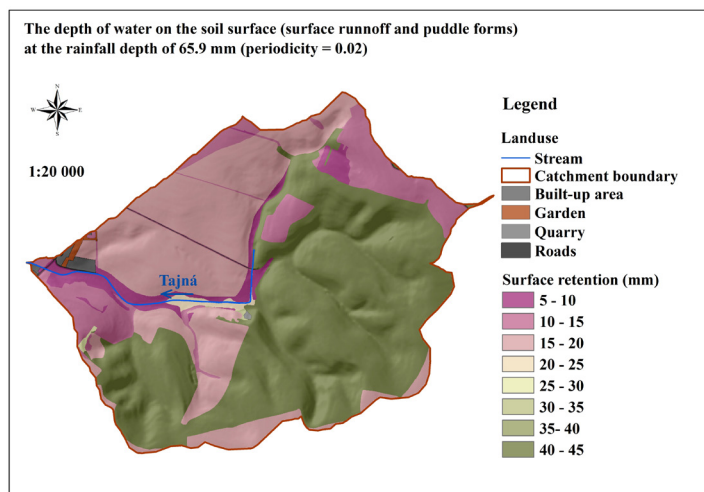
*Figure 1. Potential surface retention (mm) of the study area estimated according to CN method*

The depth of surface runoff for other landuse categories can possibly rise up to 48 mm (at $H_{D,R}$ = 53.8 mm), resp. up to 60 mm (at $H_{D,R}$ = 65.9 mm). According to the proposed methodology, the specific zones where $H_{D,R}$ exceeded $H_{R,i}$ were determined as areas with risk of soil degradation formation by water erosion.

These results can be used for the purposes of preliminary assessment in various areas of landscape planning and watershed management (Ishtiyaq, Vivek, Mukesh Kumar, 2015). The importance of the results increases with the depth of the estimated surface runoff and its location according to specific landuse types (build up areas, water dams, etc.).

The calculation procedure can be extended taking into account various further characteristics of the catchment, such as flow accumulation (Šinka, 2009) to calculate only the depth of the surface runoff, but also its volume, sediment delivery ratio and other characteristics of erosion-deposition processes (Šinka, Muchová, Konc, 2015; Kondrlová, 2009). Besides with more detailed approach also the requirements on the obligatory input data and GIS skills will increase.

It is obvious, that the performance of this approach is highly dependent on the precise CN value estimation. Besides the landuse, soil cover quality and soil type characteristics, also the antecedent moisture conditions of soil prior to specific rainfall event need to be taken into account considering the fact that more moistened soil will have lower retention capacity than the dry soil.

Chow (1964) presents CN value conversion table for individual antecedent moisture condition groups (AMCs). Calculation of the CN values for AMC-I and AMC-III is possible also by using the calculations present by Ishtiyaq, Vivek, Mukesh Kumar (2015).
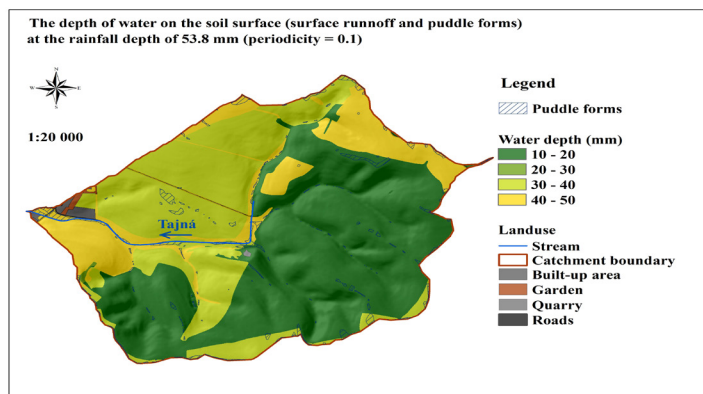
Figure 2. The depth of water on the soil surface (surface runoff and puddle forms) at the rainfall depth of 53.8 mm (periodicity = 0.1)
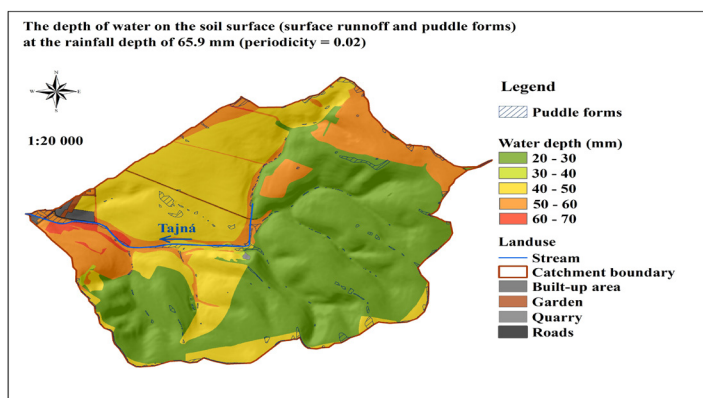


Figure 3. The depth of water on the soil surface (surface runoff and puddle forms) at the rainfall depth of 65.9 mm (periodicity = 0.02)

## Conclusions

A methodical approach presented in this study enables to localize the specific zones where $H_{D,R}$ exceeds $H_{R,i}$ and thus areas that are at the risk of soil degradation formation by water erosion by using simple but worldwide-used curve number method. The advantage of the proposed approach is that inputs for this method are generally available for the whole Slovakia (and probably for the other countries too) as well as the fact that this approach can be successfully implemented into the GIS interface. Only basic up to moderate GIS skills are required to perform the analysis what potentially makes this procedure suitable and attractive for planners and environmental managers for the purposes of the preliminary assessment of water erosion risk at the catchment scale.

**Acknowledgement**

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