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THE DESIGN OF THE SOIL EROSION AND FLOOD CONTROL SYSTEMS IN THE VILLAGE SEBEDÍN - BEČOV

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Abstrct

This paper deals with analyzed research of the rainfall – runoff process, calculation and modeling physical degradation of soil caused by water erosion. The analysis was based on an example of a model basin, where flash floods from surrounding adjacent fields cause flooding in the village, threatens residents and their property, damages the shores of the streams, and reduces the capacity of the channel by the deposition of stones and gravel. Flash flood is collected from the catchment area of about 2.5 km long wooded valley of Sebedín stream. The example micro-watershed is located in in Central Slovakia in the Banská Bystrica District, in the village of Sebedín-Bečov in the area of 383 ha. The catchment land use structure is dominated by grassland - 44%, arable land covers - 35%, forests account - 17% and urban areas - 2%, water areas - 1% and gardens. The result is the opinion of the intensity of the threat of agricultural land by water erosion using the USLE equation. Mutual share between calculated and acceptable erosion (by STN 75 4501) was expressed erosion risk of soil (so called erosion risk index). Based on the rainfall – runoff process (CN method) and the determination of the intensity of the water erosion of the soil (universal soil loss equation) in the model area, a map of draft and measures was prepared.

Key words: universal soil loss equation, water erosion intensity, erosion risk, USLE, rainfall – runoff process

Introduction

Soil erosion is a natural process often manifested by irreversible changes in the physical, chemical and biological properties of soils (Bielik, 2008). It is a physical phenomenon resulting in the removal of soil particles by the mechanical action of exogenous factors characterized by a certain kinetic energy such as rain, flowing water and wind, rarely ice, melting snow and animals. In our soil-climatic conditions, water erosion is the most common occurrence. The erosion process itself includes partial sub-processes by which the soil material is released, transported and sedimented (Fulajtár and Janský, 2001).

The most widely used methods of calculating the soil load by erosive water activity include the Wischmeier-Smith universal soil loss equation (Wischmerier and Smith, 1965, 1978). Also known as USLE - Universal Soil Loss Equation. The development of the universal soil loss equation is considered to be one of the most influential works of the twentieth century in the field of soil and water protection. On develop the universal equation have worked a few for decades universities and scientists from the whole of United States. The universal equation, as a complete technology, was first published in 1965 in the Agriculture Handbook of the United States Department of Agriculture No. 282. In 1978, a supplementary version of the equation was published in Guide 537. The equation has been compiled from a large number of empirical measurements in the United States of America, and its modified forms for other climatic, soil and vegetation areas are used worldwide. According to Antal (2005) there is no natural soil surface that would not be threatened by water erosion.

Flood is the transient flooding of the watercourse area caused by the rise of the water surface above the banks. The concept of floods is considered to be the feature at which the flow level rises to a level that can be regarded as generally dangerous (Veľký et al., 1980). It is usually a natural disaster that occurs due to sudden or unexpected changes in the meteorological situation.

In law no. 7/2010 Coll. on flood protection, a flood is defined as a natural phenomenon in which water temporarily floods a territory that is not usually water. The flood arises as a result of:

- increase in water flow in the watercourse,
- conditions will arise or creating an obstacle in the watercourse, on the bank of the stream or on a building, object or on an apparatus crossing the watercourse that caused the outpouring of water and spilling it into the adjacent area,
- prolonged precipitation or intense precipitation, snow melting or the occurrence of these phenomena,
- water inflow from precipitation or water inflow from melting snow over the surface from the adjacent area,
- groundwater level rise over surface due to long-lasting high water status in adjacent water flow or due to long-lasting rainfall.

Material and methods

The village of Sebedín-Bečov is located in central Slovakia in the Banská Bystrica district, 13 km northeast of Zvolen and 15 km southeast of the town of Banská Bystrica. As of 31 December 2015 the village has 375 inhabitants, the population density is 38.32 inhabitants / km². It is located in Poľana mountain range in the valley of the Zolná stream. The total area of the studied area is 383 ha.

The village has climatic conditions between the oceanic and continental climates. The warmest is July with an average temperature of 18.5 °C, the coldest is January with an average temperature of -4.5 °C. The yearly average is 5.5 °C. The long-term annual precipitation diameter is 700 mm and the vegetation period is 400 mm. Snow cover of 25 to 50 cm is 3-4 months. The village extends into the slightly warm climatic region.

The watercourses form a diverging river network, falling into the Hron sub-basin. The main stream is the Zolná stream. Its tributaries are Sebedín (Čiačov) and Bečov stream.

The basic for determination of the intensity of water erosion in the area is:

- vector map,
- base map in scale 1 : 10 000,
- georeferenced ortofotomap,
- geological map of Slovakia in scale 1 : 50 000,
- updated map BPEJ,
- forest soil types in scale 1 : 10 000,
- forest types in scale 1 : 10 000,
- water management district map in scale 1 : 50 000.

For the erosion risk analysis of the soil by aqueous erosion, the modified USLE equation by Wischmeir, Smith (1978) (1). The slope length and slope steepness factor has been replaced by the LS (topographic) factor, which is based on slope and slope length (Šimonides, 2000) (2).

$$SP = R.K.L.S.C.P \qquad (1)$$

$$SP = R.K.LS.C.P \qquad (2)$$

Sp – loss of soil caused by water erosion [$t.ha^{-1}.\ year^{-1}$]
R – rainfall-runoff erosivity factor [$MJ.ha^{-1}.cm.h^{-1}$]
K – soil erodibility factor [$t.MJ^{-1}$]
L – slope length factor [-]
S – slope steepness factor [-]
C – cover management factor [-]
P – support practice factor [-]
LS – topographic factor [-]

Factor R is calculated as the sum of the total kinetic energy of the rain and its biggest 30 min. of intensity. The necessary data should be obtained from omrographic rain records for at least 50 years (Mališek, 1990) (3).

$$R = E \, . \, I_{30} \qquad (3)$$

R – rainfall – runoff erosivity factor [$MJ.ha^{-1}.cm.h^{-1}$]
E – total value kinetic energy of rain [$J.m^{-2}$]
I_{30} – 30 minute intensity of rain [$cm.h^{-1}$]

For R factor we used the value measured in Banská Bystrica R = 19.9 taken from the work Identify the threat of soil quality by water and wind erosion and suggestions of measures by the authors Ilavská et al. (2005).

Factor K is defined as the soil yield per unit of rain factor R from unit land. The Soil erodibility factor (K factor) characterizes the soil particles resistance to particles detachment and transport by water. It depends on the soils intrin- sic properties and their evolution under the influence of cultivation techniques (Roose and Sarrailh, 1990). We used K factor (Ilavská et al. 2005): 0.3 – 0.72.

The slope influence length factor (L - factor) and slope (S - factor) were replaced by the LS factor in the revised USLE equation, which expresses the effect of the topography on the quantities of pre - transported soil. The significance of the shape of the area is mainly from the point of view of formation of the surface runoff, as the indirect proportionality applies: with the increasing rate of surface runoff the time for infiltration of water into the soil profile decreases. Relief is involved in the formation and course of water erosion by slope length and slope. The LS factor value is expressed by (4):

$$LS = \sqrt{l_d} \, . \, (0.0138 + 0.0097 \, . \, s + 0.00138 \, . \, s^2) \qquad (4)$$

LS – topographic factor [-]
l_d – uninterrupted slope length [m]
s – slope [%]

For the calculation of LS factor we also took into account barriers such as: water courses, roads, urban areas, non forest woody and forests (Šinka and Konc, 2014). The topographic factor value is 0 - 63 with an average of 2.23.

Vegetation Protection Factor (C - factor) is defined as the ratio between the intensity of erosion in the soil with the vegetation cover and the intensity of erosion on the cultivated eel at the same effect of other factors (Wischmeier and Smith, 1978). Factor C values for individual elements of the secondary landscape structure were taken from author Alena (1986): 0.005 for grassland; 0.61 – 0.11 for arable land; 0.82 for field road.

The anti-erosion efficiency factor defines the ratio between the intensity of erosion in the area investigated and the applied erosion measures and the intensity of erosion on the same plot of land cultivated. Since there is a lack of land housekeeping data, we have determined P factor = 1 for study area.

According to the above equation we calculated the potential and real erosion of the agricultural land.

Limit values soil transport for water erosion are given in STN 75 4501: Hydromelioration. Erosion protection of agricultural land. Basic provisions. For each category of soil depth, the following limit values are given: shallow soil (do 30 cm) – 1 $t.ha^{-1}.year^{-1}$, medium deep soil (30 – 60 cm) – 4 $t.ha^{-1}.year^{-1}$, deep soil (60 – 90 cm) – 10 $t.ha^{-1}.year^{-1}$.

The reciprocal share between the calculated and permissible erosion expressive the erosion threat of the soil and we call it the erosion threat index. We have classified this threat index into 5 classes of soil erosion risk (SEOP), tab. 1.

Table 1 Index of the degrees of erosion threatening soil – adapted according to Alena (1986)

SEOP	Name of degree of soil threated (SEOP)				
	Not threatened or slightly threatened	Medium erosion risk of soil	Distinctly erosion risk of soil	Very distinctly erosion risk of soil	Catastrophic erosion risk of soil
Classes SEOP	1	2	3	4	5
Index SEOP	< 1.00	1.01 – 2.00	2.01 – 7.00	7.01 – 28.00	> 28.00

On the basis of hydrological analyzes, we have determined the catchment profile of the basin (ZPP 1), which is a collecting basin. Water from this area (383 ha) causes local floods in the lower urban area, and water-borne material causes damage to the population's property and the infiltration of the Sebedín stream and the river Zolná.

The CN method was derived from long-term observations of drains from different river basin types. Nowadays a very advanced method for calculating the characteristics of surface runoff from agricultural basins is the so-called Method of drain numbers, abbreviated CN-method. The CN method is derived from agricultural exploited basins, taking into account, in addition to the hydrological characteristics of the basin, the way of its agricultural use.

The basis of the CN-method is to determine the CN value of the investigated basin, the value of which ranges from CN = 0 to CN = 100. The value of CN = 100 means that all rainwater falling into the basin, Its part flows as a surface drain. The value of CN = 0 means that all the rainwater infiltrates into the soil. The value of CN is a function of the characteristics of: - the soil in the catchment area, - the vegetation cover, - the method of cultivation of the soil, - the moisture state of the soil.

For hydrological analysis, we chose the calculation using a detailed CN-method solution (D-CN). Characteristic for D-CN is that for each representation CN value, the height of the potential retention (5) and height of the surface drain (6) (Šinka et. al. 2015).

$$A = 25.4\,.(\frac{1000}{\text{CN}} - 10) \qquad (5)$$

A – potential retention [mm]

CN – value CN [-]

$$\text{H}_{O,P} = \frac{(H_{D,N} - 0.2\text{A})^2}{H_{D,N} + 0.8\text{ A}} \qquad (6)$$

$H_{O,P}$ – surface drain height [mm]

A – potential retention [mm]

$H_{D,N}$ – height of the draft rain [mm]

We determined the value of the CN using the main soil unit from the BPEJ code on agricultural land and forest soil based on forest soil types. To take into account and to clarify the volume of surface runoff we have added the so- weight on the whole basin with the help of direction draining ratios (Kaletová and Šinka, 2012). The calculation was made in ArcGIS 10.2.2, which we also applied to all graphic representation and modeling of the territory. Results of water management and counter-analysis are shown in fig. 1

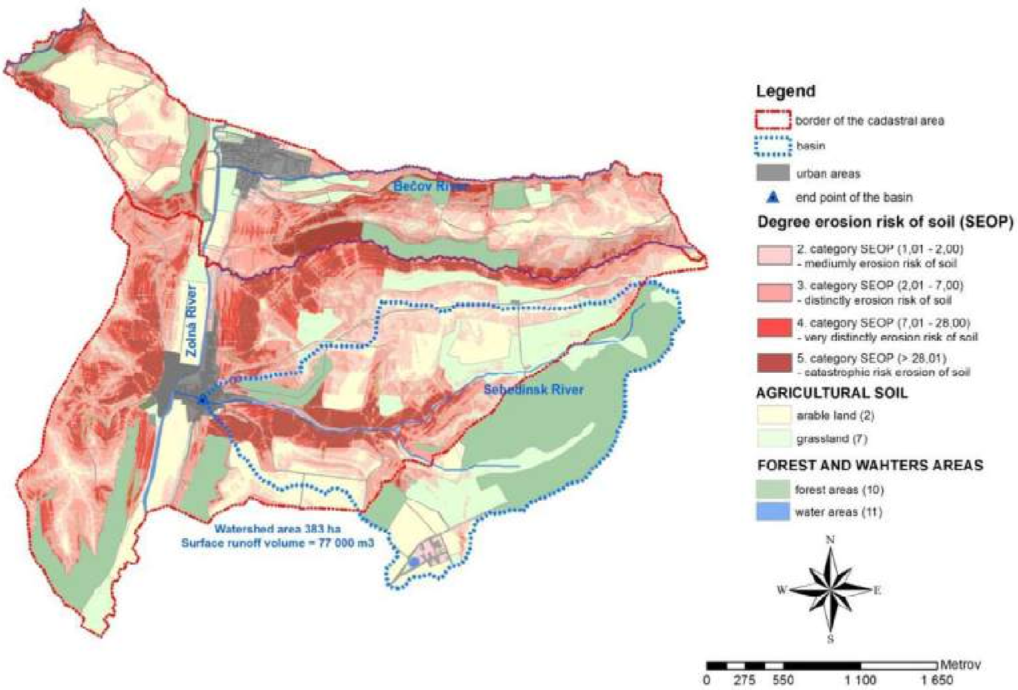

Figure 1. Analytical map

Results and discussion

Based on the topographic map and the orthophotomap, we specified 6 types of land use (fig. 2). The largest representation in the analyzed area has grassland with a percentage of up to 44% and arable land with a share of 35%. The solution of the territory is situated in the foothill area, therefore the logical prevalence of the grassland.

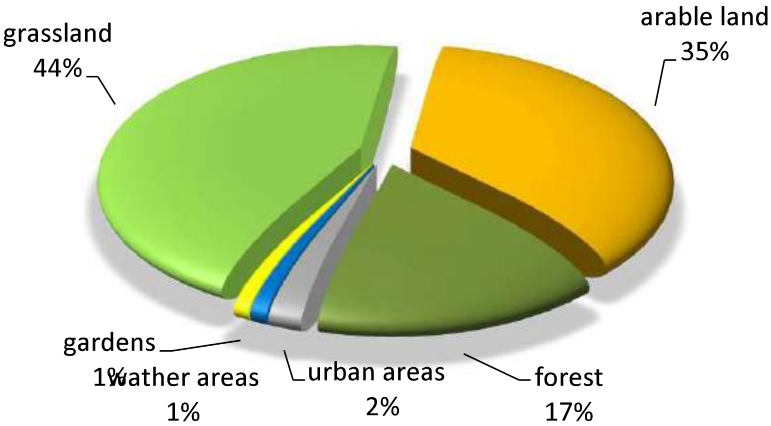

Figure 2. Representation of land types in the analyzed area

In the solution area was draft, on the base processed analytic test, two anti-erosive tanks (PN 1, PN 2), a recess anti-erosive terrace (TER 1 to 3), a gabion system weir (PREH-G 1 to 4) and wooden weir (PREH-Z 1, PREH-Z 2). Their draft is a complementary system of supporting organizational and agrotechnical measures (fig. 3).

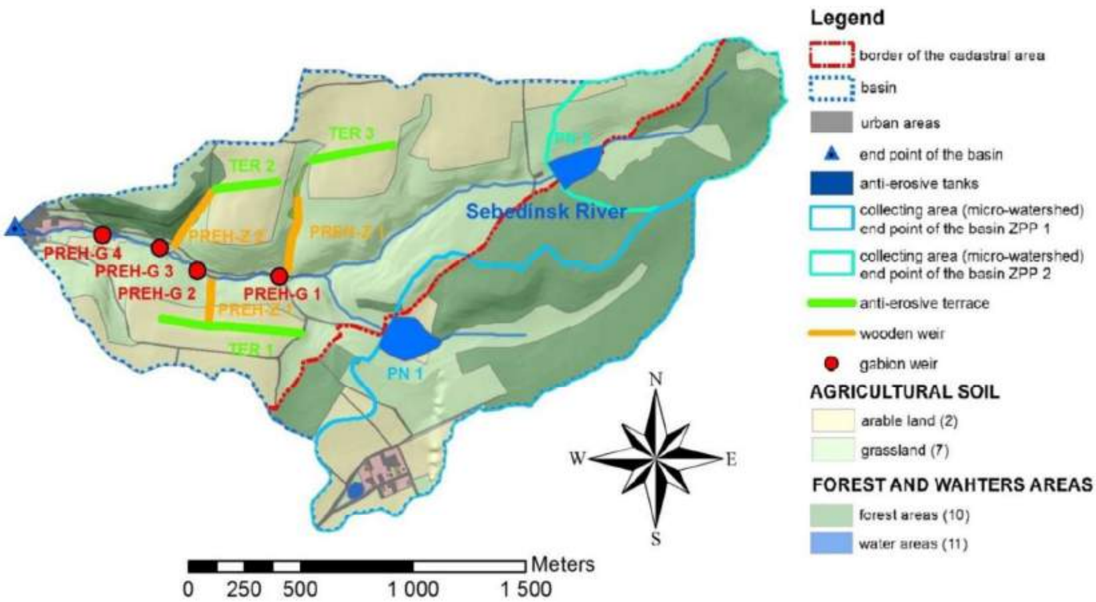

Figure 3. Draft map

Anti-erosion reservoirs - The position of the anti-erosion tank PN1 is located, for the most part, in cadastral area Zolná. The reasons for the location of the tank beyond the boundary of the solution area are more suitable morphological ratios. The area of collecting micro-watershed is 102 ha and the captured volume is about 20 800 m^3. The current type of land is 82% of arable land and 18% of grassland. PN2 is draft at the boundary to cadastral area Sebedín and Očová. The reason for the location of the collection tank at the boundary of the solution area was similar to that of the anti-erosion PN 1. The area of the collection area is 55 ha and the captured volume is 5300 m^3. The current type of land in the territory is grassland 74% and forest land 26%.

Depression anti-erosion Terraces - Arresting depression anti-erosive terraces (terraces, fig. 4 - Cut a depression anti-erosive terrace) are draft on the contour. It divides large blocks of soil on a slope, interrupting the slope. Function terraces are the retention of precipitation water and its innocuous flow into the borehole in its part, but especially the sediment retention, the material in the site of the soil block above the barrage in the problem site, in the Sebedín brook. Recess terraces are designed in a length of 650, 450 and 300 m and a width of about 10 m with a drainage element grassed with planting trees and trusses for more effective sediment retention and avoidance of possible disintegration.

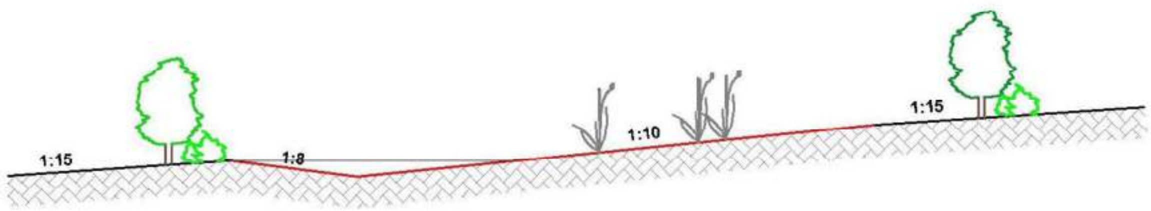

Figure 4. Section depression erosion terrace

Weir - The main purpose of the weir is to stabilize the bottom of the flow with a large slope. These transverse structures serve to stabilize and reduce the longitudinal decline to prevent erosion. The weir is also used to catch the floats, which are the main cause of the limitation of the flow or the clogging of the critical profiles. For our location, we have draft gabion compartments. Their advantage is shape variability, the possibility of any height, length, shape and aesthetics (natural material). In our proposed territory we designed four gabion weir (PREH-G 1 to 4). When placing individual compartments, we proceeded from the longitudinal slope of the water flow.

The wooden weir performs the same purpose as the gabion weir. Their use is mainly applied in the steepest watercourses (streams) that pass through forest land. The advantages of these weir are the simplicity, the use of natural material and hence the availability of building materials for construction. For better effect, the so-called A system of wooden weir. In the studied area, we chose two localities where we draft to implement them. The first set of wooden weir (PREH-Z 1) is situated from the central part of the study area and its influx is just in front of the gabion weir. Based on preliminary calculations, the wooden weir system could capture approximately 10500 m^3 of 41 ha. The second set of weirs (PREH-Z 2) is located in a natural burrow on forest land in the eastern part of the studied area. The volume of captured surface runoff of the second set of weir is 4,000 m^3 of an area of 29 ha.

Conclusions

Based on the precipitation-runoff analysis process (CN method) and the determination of the intensity of the water erosion of the soil (universal soil loss equation) in the model territory, we have draft:

- Two anti-erosive tanks, a depression anti-erosive terrace, a system of gabion and log cabins.
- Water reservoirs could contain water from area 155 ha of 26100 m^3.
- The depression terrace is draft with a length of 650 m and a width of approx. 10 m with drainage element, grassed with trees and roof trusses.
- We draft a system of gabion and log cabins for the purpose of stabilizing ridges in the valleys of watercourses, accumulating part of the volume from flood local floods and collecting sediments from nearby adjacent locality.

The proposal for technical measures has been supplemented by a system of supporting organizational and agro-technical measures (eg. excluding the cultivation of little susceptible crops for erosion, shaping of soil units, etc.). The calculated value of the actual erosion in the area for the cultivation of the current crops, the area is extremely threatening. The modeling shows that the most effective measure on agricultural land is the choice of growing crops (barley, wheat) and clover-grasses, in combination with contouring soil cultivation. On wooded slopes with a slope of 19-69° it is necessary to make changes in the species composition of forests in favor of the composition of natural vegetation.

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