USE OF THE USLE 2D MODEL TO ASSESS THE IMPACT OF ANTI-EROSION MEASURES ON THE EXTENT OF POTENTIAL WATER EROSION IN THE RESEARCH AREA OF SOBOTIŠTE

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Abstract
The article focuses on assessing the impact of anti-erosion measures on soil water erosion implemented at the Sobotište research site, covering an area of 68 ha. The anti-erosion measures consist of two water retention grass ditches located in the lower part of a slope and a change in the management of the entire slope. The assessment twas conducted by comparing slope conditions before and after implementing anti-erosion measures using the Universal Soil Loss Equation (USLE) and the USLE2D sub-model, which calculates the LS topographic factor. The modelling was conducted in the ArcMap software environment with a digital relief model resolution of 1 × 1m and the LS topographic factor calculation algorithm according to the author McCool [1].

Keywords
USLE 2D, topographic factor, anti-erosion measures, modelling, ditches

1 INTRODUCTION

An increasingly discussed trend in science is the rising rate of soil erosion, especially water erosion. It is a complicated degradation, relief-creating soil process, which is currently perceived as a global threat requiring attention from the world's leading scientists and experts.

The existence and emergence of erosion processes contributing to soil degradation result from the interaction of natural factors, anthropogenic influences (human intervention) and, last but not least, manifestations of climate change, mainly the alternation of heavy rains and periods of drought.

Globally, population growth is driving increased demand for food, particularly in agriculturally cultivated areas. Moreover, agricultural areas are especially prone to soil erosion or water soil erosion. According to the Food and Agriculture Organization (FAO), six types of soil degradation can be distinguished, with water erosion being the most widespread worldwide. In the Slovak Republic, approximately 40% of arable land is potentially at risk, according to the study "Development of soil erosion trends and organic matter content in the soil for the evaluation of PRV SR 2014-2020". For more details, refer to [7].

As a result of water erosion, soil experiences serious negative consequences, including a decrease in soil profile depth, deterioration of soil structure, and loss of nutrients and organic matter. The 2019 Sartori study [6], prepared by the Joint Research Centre of the European Commission, has also contributed research and talks about the figure of eight billion dollars, which represents the amount of money the world economy loses annually due to water erosion. The mentioned study is one of the first of its kind to quantify soil productivity losses on a global scale, highlighting that up to one-quarter of arable land worldwide is affected by serve water soil erosion.

"Soil erosion „refers to a complex process, involving the disturbance of soil surfaces and the transport and sedimentation of loosened soil particles by water, wind, ice and other erosion factors, including human aktivity [4]. These influences impart kinetic energy to soil particles, causing them to loosen and move [3]. Water erosion is caused by the destructive impact of atmospheric precipitation and surface runoff, which disturbs the soil surface.

This contribution is focused on evaluating soil erosion using the USLE empirical model, employing the USLE-2D sub-model in a selected experimental basin in western Slovakia in the cadastral territory of the municipality of Sobotište (Fig. 1).

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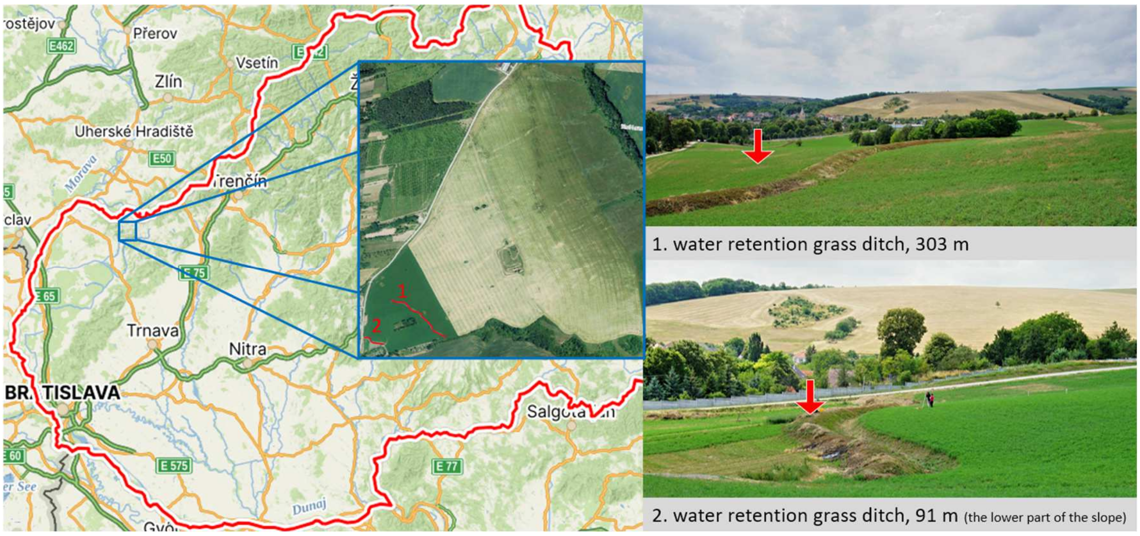

Fig. 1 The assessed area - the village of Sobotište, western Slovakia.

Specificaly, the Universal Soil Loss Equation (USLE) was used to assess the impact of existing technical anti-erosion measures, consisting of two water retention grass ditches in the lower part of the assessed slope. Additionally, the USLE was employed to assess the impact of changes in the organization and management of crop cultivation and slope management.

2 METHODOLOGY

The area of interest comprises 68 ha and is situated in the cadastral territory of the municipality of Sobotište in western Slovakia. The average slope of the area is 7° (max. 31°) and the soil type is loamy. The average annual rainfall is 650 to 700 mm, with a humid and warm climate featuring mild winters.

Existing anti-erosion measures were implemented on this slope in 2011. To assess their impact, we compared the results modelled using the USLE before and after their implementation, employing the USLE 2D (Fig. 2). In the mentioned picture, there is an orthophoto map from two periods (specifically 2011 and 2015), illustrating the location of infiltration ditches and the changes in slope management and crop distribution.

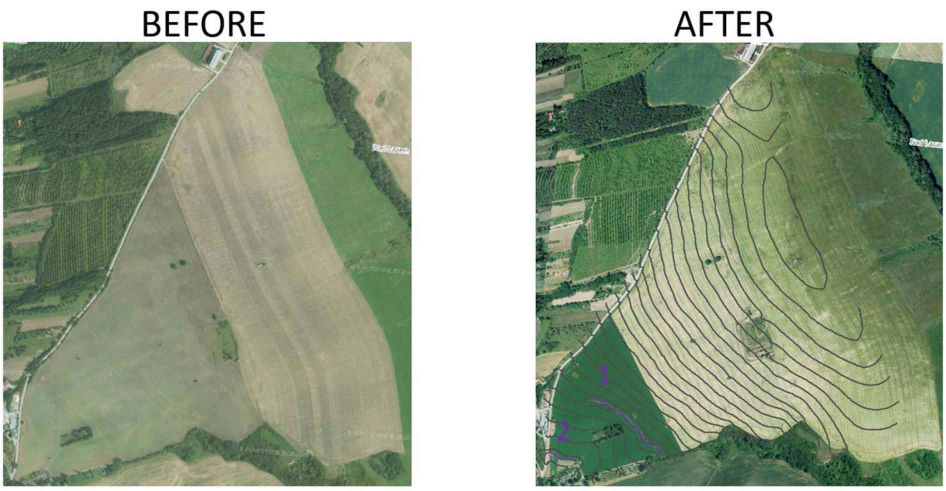

Fig. 2 State of the slope assessed before and after implementation of anti-erosion measures in 2011.

The following table (Tab. 1) shows the values and specifications of the factors entering the Universal Soil Loss Equation (1), i.e., the product of causative factors that affect soil erosion caused by torrential rain. The LS topographic factor was calculated using the algorithm developed by McCool et al. [1] [2]. The reason for choosing the algorithm is its objective appropriateness for the region of western Slovakia, as highlighted in the study "Prevention and elimination of the consequences of soil erosion, building eco-stabilization elements in the country

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and development of selected elements of green infrastructure for the protection and coordinated management of naturally significant cross-border areas" [8].

$$G = R \cdot K \cdot L \cdot S \cdot C \cdot P, \tag{1}$$

where G is average annual soil loss in t · ha^{-1} · year^{-1}, R is rainfall erosivity factor in MJ · ha^{-1} · cm.h^{-1}, K is soil erodibility factor t · ha^{-1} · year^{-1}, L slope length factor (dimensionless), S slope factor in %, C cover and management factor (dimensionless) and P support practice factor (dimensionless) < 0 ~ 1 >.

Tab. 1 Factors Entering the Universal Soil Loss Equation [10].

Var.	**LS Topographic factor (slope length and steepness) [-]**	**R Rainfall erosivity factor [Mj.ha^{-1}.cm.h^{-1}]**	**K Soil erodibility factor [-]**	**C Cover and manag. factor [-]**	**P Support practice factor [-]**	**Anti-erosion measures (grassy growth)**
A	*Computation based on USLE 2D (McCool, 1987)*	***59.9***	***0.17 – 0.4***	***0.10/0.17*** spring wheat/winter barley	***1***	*No, before 2011*
B		***59.9***		***0.02/0.12*** *lantern/winter wheat*	***0.8***	*Yes, after 2011*

** Variant A – state of the slope before the implementation of anti-erosion measures, Variant B – state after their implementation.*

The factors were prepared using the ArcMap software environment and incorporated into the USLE model, both in map and numerical formats – Fig. 3. Specifically, the factors LS, R, K, and C were presented as maps, while factor P was expressed as a numerical value (Var. A: P = 1, Var. B: P = 0.8). The K-factor was determined based on BPEJ by georeferencing the soil map obtained from the VÚPOP portal [5]. The R-factor was calculated using the original methodology based on minute data recorded between 1995 and 2009 for the summer months (Myjava station, ID – 15020). The slope was divided into two parts based on the C-factor, representing the protective effect of vegetation. Each section had a different value of the C-factor with respect to the crop cultivated – Tab. 1.

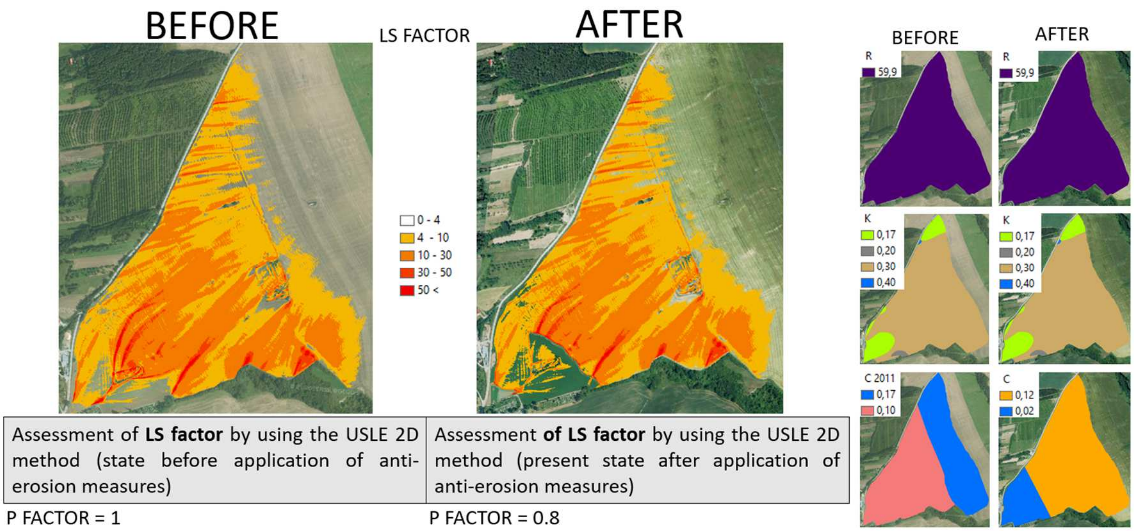

Fig. 3 Preparation of factors such as maps and numerical values for USLE.

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3 RESULTS

Using this comparative modelling, it was possible to demonstrate the impact of proposed anti-erosion and anti-flood measures, especially in the lower part of the slope where two water retention grass ditches were built by grassing the lower part – Fig. 4. Our analysis indicates that the territory and structures under the slope help to eliminate the adverse effects of soil water erosion. However, the total amount of erosion within the assessed slope decreased by only 2.46 t/ha/year from the original 16.7 t/ha/year (representing a 14% reduction).

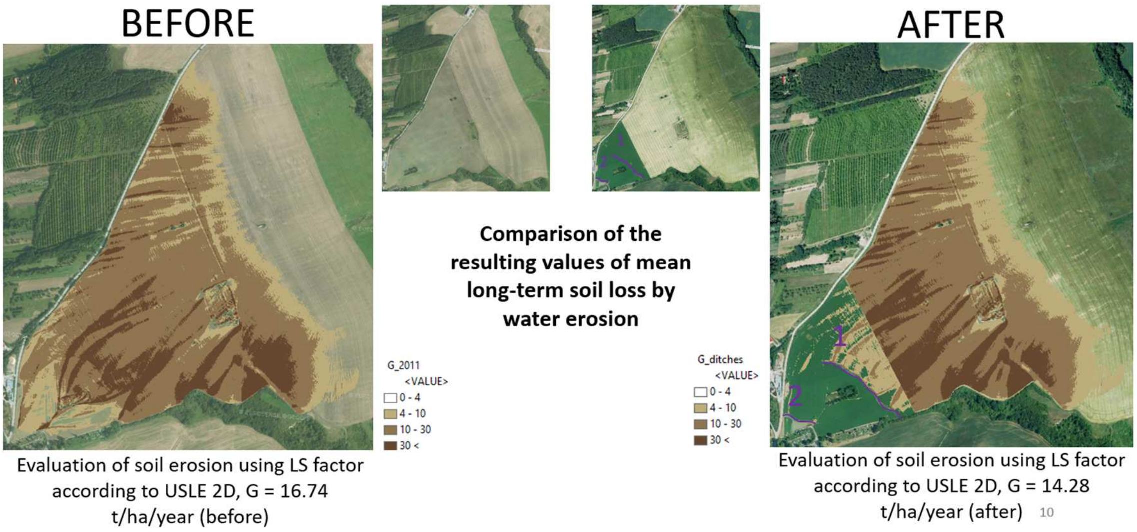

Fig. 4 Comparison of average annual soil loss due to water erosion in t/ha/year.

For this reason, a new anti-erosion measure has been proposed in the form of building another water retention grass ditch, in order to reduce the extent of potential water erosion and further reduce overall soil erosion. As a suitable location, we chose the upper part of the slope, specifically in its non-grassed part (refer to the longitudinal profile of the slope is in Fig. 5).

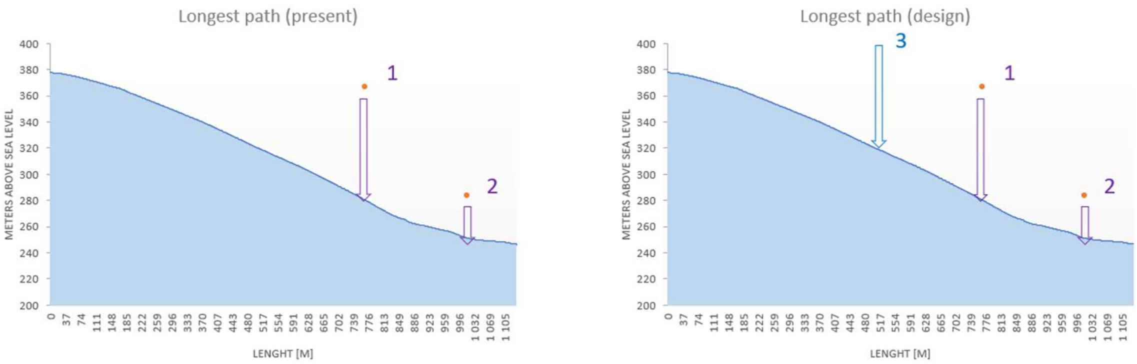

Fig. 5 Longitudinal profile along the slope.

The following image – Fig. 6, shows the design of the third infiltration ditch situated in the first third of the upper part of the slope, with its location marked along the contour line. Maps are also shown as graphic representations of the factors entered into the Universal Soil Loss Equation for calculating the average annual soil loss, considering the impact of the proposed new anti-erosion measure, namely, the third water retention grass ditch.

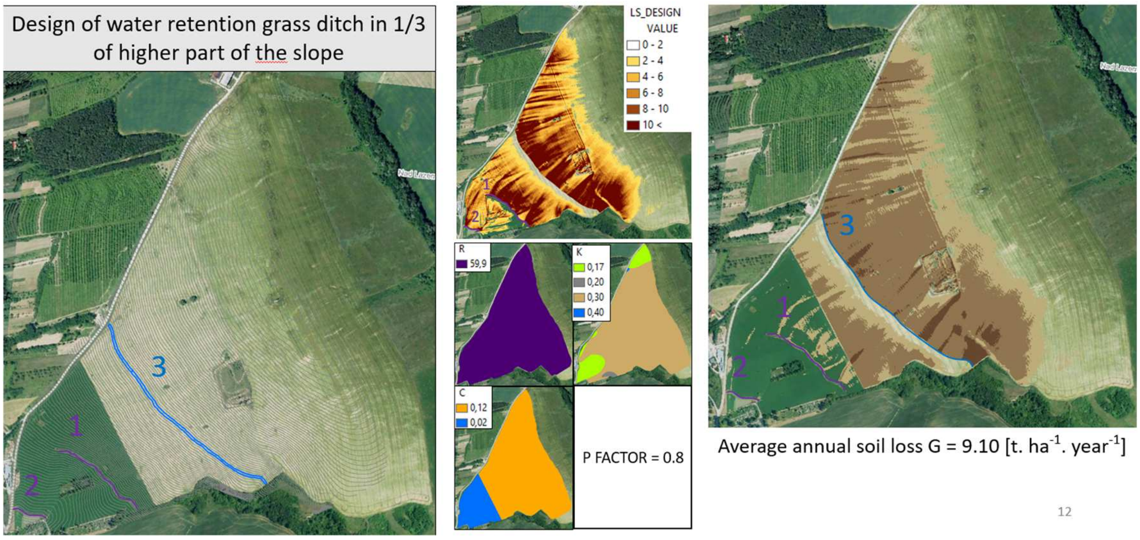

Fig. 6 Location of the third water retention grass ditch within the slope, maps of the factors entered into the Universal Soil Loss Equation, graphic and numerical representations of the resulting average annual soil loss, affected by the proposed new erosion control measures.

Fig. 7 graphically shows the results of modelling the average annual soil loss within the assessed slope under various anti-erosion protection conditions. While the permissible soil loss limit 4 t/ha/year within the entire slope [11] was not achieved, the proposed anti-erosion measures effectively slow down water erosion of the soil, particularly in the upper part of the slope. In the lower part of the slope, the relationship between soil and sediments due to water erosion is captured, which also is expected to prevent silting.

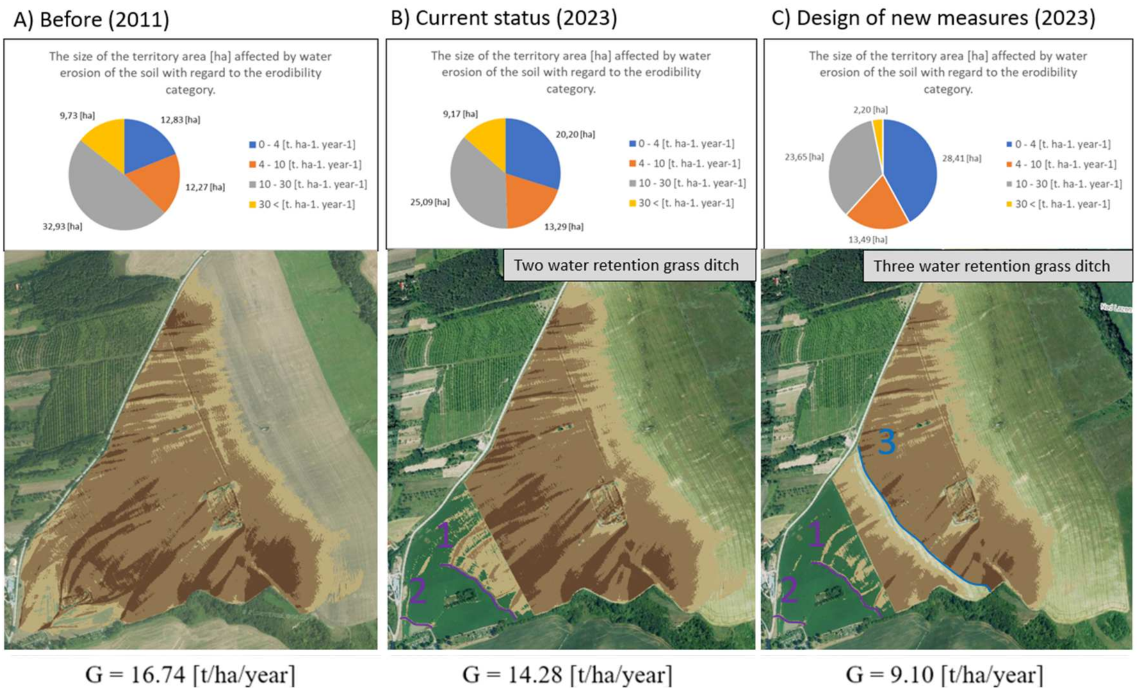

Fig. 7 Comparison of the modelled state of the slope before 2011, the current state and the proposed state.

4 DISCUSION

In Fig. 7, it can be seen that comparing the erodibility rates between categories such as "none" and "extreme" – Tab. 2, within the considered slope reveals the following. The average annual soil loss in the "extreme" category is reduced to a minimum, while it dominates in the "none" category.

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Tab. 2 Threshold values for categories of erodibility.

Category of erodibility	Average annual soil loss
1 – None	*0 – 4 t · ha⁻¹ · year⁻¹*
1 – Medium	*4 – 10 t · ha⁻¹ · year⁻¹*
1 – High	*10 – 30 t · ha⁻¹ · year⁻¹*
1 – Extreme	*> 30 t · ha⁻¹ · year⁻¹*

Since we managed to affect to some extent the average annual soil loss within the entire assessed slope, a possible additional measure or proposal would be a change of management within the upper part of the slope (ploughing along the contours, strip cultivation of the crops), or a change of the cultivated crop itself (narrow row crops or weeding).

5 CONCLUSIONS

This paper aimed to model and evaluate the impact and effectiveness of existing anti-erosion measures on a slope using the USLE2D methodology. The modelling results confirm the efficiency of the two designed and implemented water retention grass ditches in the lower part of the slope. However, the comparison revealed the need for a new proposal: the addition of a third linear element to protect the entire territory. The necessity arises from inadmissible values of potential soil erosion in the upper part of the slope, which could impact the dynamics of the silting of existing infiltration ditches. By interrupting the surface runoff with a supplementary drainage ditch in the upper part, the erosion activity would be reduced, along with the issue of their maintenance and the capacity of existing ditches. The unfavourable state of silting in existing ditches was pointed out in a study [9], evaluating sediment dynamics using spatial data collected by a terrestrial laser scanner and an unmanned aerial vehicle.

Considering these results, adjusting local land management and choosing crops with higher anti-erosion effects would be advisable.

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References

[1] MCCOOL, D. K., BROWN, L. C., FOSTER, G. R., MUTCHLER, C. K. and MEYER, L. D. Revised Slope Steepness Factor for the Universal Soil Loss Equation. *Transactions of the ASAE* [online]. 1987. Vol. 30, 1387–1396. DOI 10.13031/2013.30576

[2] MCCOOL, D. K., BROWN, L. C., FOSTER, G. R., MUTCHLER, C. K. and MEYER, L. D. Revised Slope Length Factor for the Universal Soil Loss Equation. *Transactions of the ASAE* [online]. 1989. Vol. 32, 1571–1576. DOI 10.13031/2013.31192

[3] FULAJTÁR, E., JANSKÝ, L. Vodná erózia pôdy a protierózna ochrana (Water soil erosion and anti-erosion protection). Bratislava: *Research Institute of Soil Science and Soil Protection*, 2001. ISBN 80-85361-85-X

[4] JANEČEK, M. Ochrana zemědělské půdy před erozí: metodika. Praha: Power print, 2012. ISBN 978-80-87415-42-9. Translated to English: Protection of agricultural land from erosion: methodology.

[5] Parametre BPEJ, *NPPC-VÚPOP, EUROSENSE s.r.o., GEODIS s.r.o.* [online]. [cit. 28.10.2023] Available at: https://portal.vupop.sk/portal/apps/webappviewer/index.html?id=d89cff7c70424117ae01ddba7499d3ad

[6] SARTORI, Martina, PHILIPPIDIS, George, FERRARI, Emanuele, BORRELLI, Pasquale, LUGATO, Emanuele, MONTANARELLA, Luca and PANAGOS, Panos. A linkage between the biophysical and the economic: Assessing the global market impacts of soil erosion, *Land Use Policy. Elsevier*. 2019. No. 86, pp. 299–312. Available at: https://doi.org/10.1016/j.landusepol.2019.05.014

[7] STYK, Ján and PÁLKA, Boris. Vývoj trendov erózie pôdy pre hodnotenie PRV SR 2014–2020 (Development of soil erosion trends for the evaluation of the PRV SR 2014-2020). [online] 13.5.2020 [cit. 28.10.2023]. Bratislava, 2019. Available at: https://www.mpsr.sk/vyvoj-trendov-erozie-pody-a-obsahu-organickej-hmoty-v-pode-pre-hodnotenie-prv-sr-2014-2020/1289-43-1289-15457/. Zmluva o

dielo č. 76/2018-600/MPRV SR uzatvorená v zmysle § 536 a nasl. zákona č. 513/1991 Zb. Obchodný zákonník v znení neskorších predpisov

[8] VÝLETA, Roman, ČISTÝ, Milan, DUMBROVSKÝ, Miroslav, HLAVČOVÁ, Kamila, KOHNOVÁ, Silvia, MACURA, Viliam, SZOLGAY, Ján, FRAŠTIA, Marek, STRÁŇAI, Ivan, ŠKRINÁR, Andrej, ANDREJI, Jaroslav, DANÁČOVÁ, Michaela, MARČIŠ, Marián, REHÁČKOVÁ, Tamara, STANKOCI, Ivan and VALENT, Peter, Prevencia a odstraňovanie dôsledkov erózie pôdy, budovanie ekostabilizačných prvkov v krajine a rozvoj vybraných prvkov zelenej infraštruktúry pre ochranu a koordinované riadenie prírodne významných cezhraničných území: štúdia – kód projektu v ITMS: 304021C996 (Prevention and elimination of the consequences of soil erosion, construction of ecostabilization elements in the country and development of selected elements of green infrastructure for the protection and coordinated management of naturally significant cross-border areas: study – project code in ITMS: 304021C996). Bratislava, 2019

[9] VÝLETA, Roman, Miroslav CELLER and Michaela DANÁČOVÁ. Vplyv protieróznych opatrení na vodnú eróziu a transport sedimentov v k. ú. obce Sobotište (The impact of anti-erosion measures on water erosion and sediment transport in the cadastral area of the municipality of Sobotište). *Czech Journal of Civil Engineering* [online]. 2016. Vol. 2, no. 2, pp. 162–168. [Accessed 14 August 2023]. DOI 10.51704/cjce.2016.vol2.iss2.pp1-7

[10] WISCHMEIER, W. H. and SMITH, D. D. Predicting Rainfall Erosion Losses – A Guide to Conservation Planning. *Science and Education Administration, U.S. Dept. of Agriculture*, 1978

[11] Zákon č. 220/2004 Z. z.: *Zákon o ochrane a využívaní poľnohospodárskej pôdy a o zmene zákona č. 245/2003 Z. z. o integrovanej prevencii a kontrole znečisťovania životného prostredia a o zmene a doplnení niektorých zákonov (Act on the protection and use of agricultural land and on the amendment of Act no. 245/2003 Coll. on integrated prevention and control of environmental pollution and on amendments to certain laws)*. [online]. 2004. Available at: https://www.zakonypreludi.sk/zz/2004-220

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