Journal of Environmental Management 261 (2020) 109958

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: http://www.elsevier.com/locate/jenvman

Research article

Estimating sedimentation rates in small reservoirs - Suitable approaches for local municipalities in central Europe

David Honek [a,b,*], Monika Šulc Michalková [a], Anna Smetanová [c], Valentin Sočuvka [d], Yvetta Velísková [d], Petr Karásek [e], Jana Konečná [e], Zuzana Németová [f], Michaela Danáčová [f]

[a] Department of Geography, Faculty of Science, Masaryk University, Kotlářská 2, 611 37, Brno, Czech Republic
[b] T.G.Masaryk Water Research Institute, p.r.i., Mojmírovo náměstí 16, 612 00, Brno, Czech Republic
[c] RG Ecohydrology and Landscape Evaluation, TU Berlin, Ernst-Reuter-Platz 1, 10587, Berlin, Germany
[d] Institute of Hydrology, Slovak Academy of Sciences, Dúbravská cesta 9, 841 04, Bratislava, Slovak Republic
[e] Research Institute for Soil and Water Conservation, Lidická 25/27, 602 00, Brno, Czech Republic
[f] Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology in Bratislava, Radlinského 11, 810 05, Bratislava, Slovak Republic

A R T I C L E I N F O

Keywords:
Soil water erosion
R-factor
Sediment budget
Empirical model
Semi-dry reservoir

Small reservoirs, as the preferred blue-green engineering infrastructure for use against intensive runoff processes, have risen in number in Central Europe during the past three decades. However, the modelling of sediment siltation is not included in reservoir planning. The unknown temporal sedimentation of a reservoir can lead to the lifespan of the construction being uncertain. The aim of this study is to present a relatively simple process for local managers to model siltation and, consequently, accurately estimate the lifetime of a small reservoir. Three empirical models (USLE, RUSLE and USPED) were applied to two small catchments in Central Europe. This paper takes advantage of real measured and modelled sedimentation during 2012 and 2017, presenting two different terrain measurement approaches. Our study emphasizes the importance of the R-factor value. The temporal development of the R-factor is dependent on climate change, and the R-factor value has been rising steadily during the last decades. The annual mean R-factor has increased 1.04-times due to changes in precipitation patterns between the periods 1961–1980 and 1997–2016. These changes can explain possible growth in the levels of incoming sediment into reservoirs. We identified the correlation ($R > 0.7$) between observed sedimentation, the R-factor, and precipitation, and we concluded that the supposed rise of precipitation in Central Europe due to climate change will lead to an increase in the levels of stored sediment in reservoirs. Therefore, it is recommended for reservoir managers to use USPED model and to include the estimation of modelling of siltation rate into reservoirs' maintenance projects.

1. Introduction

The severity and distribution of precipitation in Central Europe have been changing due to climate change (Zolina et al., 2014; Dolák et al., 2017; Trnka et al., 2017), and, consequently, flash floods and flooding have become frequent occurrences in recent years (van Rompey et al., 2001; Nelson and Booth, 2002; Abril and Knight, 2004; ; Hlavčová et al., 2016). The total annual number of floods in Europe since 1871 has been

Abbreviations: AM, Aggregated Measure; AMSL, Above Mean Sea Level; AUV, Autonomous Underwater Vehicle; C, Cover and management factor; CN, Number of runoff curve; CZE, Czech Republic; DEM, Digital Elevation Model; eAGRI, Ministry of Agriculture of the Czech Republic (website); EEA, European Environmental Agency; ESDAC, European Soil Data Centre; INSPIRE, Infrastructure for Spatial Information in Europe; IPCC, Intergovernmental Panel on Climate Change; K, Soil erodibility factor; L, Slope length factor; LUCAS, Land Use and Coverage Area frame Survey; MB, Model Bias; ME, Model Efficiency; P, Support practice factor; R, Rainfall erosivity factor; *R*, Coefficient of correlation; r_{mod}, Modified correlation coefficient; RMSE, Root Mean Square Error; RRMSE, Relative Root Mean Square Error; RUSLE, Revised Universal Soil Loss Equation; S, Slope steepness factor; SAS, Slovak Academy of Science; SDR, Sediment Delivery Ratio; SHMÚ, Slovak Hydrometerorological Institute; SUC, Suchý Creek catchment; SVC, Svacenický Creek catchment; SVK, Slovak Republic; USLE, Universal Soil Loss Equation; USPED, Unit Stream Power based Erosion/Deposition model; VÚ, MOP Research Institute for Soil and Water Conservation.

* Corresponding author.
E-mail addresses: stondavid@mail.muni.cz, david.honek@vuv.cz (D. Honek), monika.michalko@gmail.com (M.Š. Michalková), anna.smetanova@gmail.com (A. Smetanová), socuvka@uh.savba.sk (V. Sočuvka), veliskova@uh.savba.sk (Y. Velísková), karasek.petr@vumop.cz (P. Karásek), konecna.jana@vumop.cz (J. Konečná), zuzana.nemetova@stuba.sk (Z. Németová), michaela.danacova@stuba.sk (M. Danáčová).

https://doi.org/10.1016/j.jenvman.2019.109958
Received 23 July 2019; Received in revised form 29 November 2019; Accepted 3 December 2019
Available online 3 February 2020

rising (Suppl. I). Generally, the significance of a geomorphological understanding of hydrological events is that it impacts the ability to design flood protection measurements that remain stable after construction, and thereby require little maintenance (Richter and Thomas, 2007; Yin et al., 2011; Nesshöver et al., 2016; Denjean et al., 2017; EEA, 2017).

Understanding the geomorphological principles as described above can lead to more natural and environmentally friendly designs, such as the construction of dry or semi-dry reservoirs/detention ponds (Richter and Thomas, 2007; EC, 2011; Yin et al., 2011; Denjean et al., 2017). A reservoir is an artificial basin excavated on a small (4th order) creek tributary to a river, which disconnects or retards the overland flow of water and sediments during mean and flood events by storing water and sediments for a limited period of time. A small water reservoir must meet one of two parameters: (1) the volume of the reservoir must be lower than 2 mil. m^3, or (2) the depth of the reservoir must not exceed 9 m (Technical norm No. CTS 75 2410).

Because of the importance of flood protection, more elaborate and concrete legislation of these structures is needed. The infrastructure of small water reservoirs is currently governed by Czech basic standards legislation (Act No.114/1992, Act No. 183/2006 and Act No. 254/2001), and their maintenance is the responsibility of local municipalities or local river managers. Multiple municipalities in cooperation with stream managers in the Czech Republic (CZE) have invested in blue-green engineering infrastructures, including small reservoirs, as maintenance solutions, and construction of these infrastructures began in early 2000. Creating a dry or a semi-dry reservoir is an effective flood control measure that can help reduce peak flow and distribute flood wave volume over a longer period of time by temporarily accumulating water (Nesshöver et al., 2016; Denjean et al., 2017; Dong et al., 2017; EEA, 2017). Traditionally, there has been little geomorphological or sedimentological cost-benefit evaluation of these particular maintenance solutions. After a flood has ceased, a dry reservoir is emptied, and the area can be used in a manner similar to or the same as its prior use. Semi-dry reservoirs, which maintain a permanent water level, may have technical, landscaping, and/or ecological functions. In both cases, the real volume of captured fine sediment (the suspended load) is unknown.

The sediment delivery ratio (SDR) is a commonly used indicator of basin sediment transport efficiency (Ferro and Minacapilli, 1995; Dickinson and Collins, 1998; Krasa et al., 2005; Taguas, 2011; Di Stefano and Ferro, 2017). According to Boyce (1975), the SDR generally decreases where increasing basin size and decreasing average basin slope occur at the same time. Large basins also have more sediment storage sites located between the sediment source areas and the basin outlet. The application of empirical models to SDR has been shown to be highly appropriate (Ferro and Porto, 2000; Taguas et al., 2011; Zhao et al., 2018).

(Dis)connectivity measures applied for water and sediment retention have been proven to have differing levels of efficiency in trapping water and sediments in different environments (e.g. Boix-Fayos et al., 2008; Fu et al., 2011; Kondolf et al., 2014; Mekonnen et al., 2014; Zhao et al., 2018). Similar to in large reservoirs (Wohl and Cenderelli, 2000; Yin et al., 2011; Baade et al., 2012; Lee and You, 2013; Lewis et al., 2013; Rahmani et al., 2018), siltation in small reservoirs decreases storage capacity and lifespan (Bazoffi et al., 1996; Bussi et al., 2013; Borrelli et al., 2014), and low-frequency high-magnitude events can promote disastrous flashing of sediments to adjacent settlements (Stankoviansky et al., 2010; Hlavčová et al., 2016). Unlike large reservoirs, however, small reservoirs in rural settings rarely have maintenance plans for addressing these issues, and municipalities often do not have enough funds to adequately maintain and manage these small reservoirs. The intensity and drivers of infilling in these reservoirs are largely unknown (Uhlířová, 2007; Yin et al., 2011; Hlavčová et al., 2018). The aim of this study is to present a relatively simple process for local managers to model siltation and, consequently, accurately estimate the lifespan of a small reservoir.

This paper will answer a key question asked by managers and stakeholders from local communities: are the empirical models (USLE, RUSLE and USPED) suitable for general estimation of potential siltation in small reservoirs? To provide an answer to this question, the aims of the study were as follows:

- To understand the infilling process in small retention reservoirs in small rural catchments;
- To discuss whether the empirical models (USLE, RUSLE and USPED) are suitable for assessment of sediment siltation in small reservoirs;
- To determine the potential correlation between R-factor values and real/modelled sedimentation rates;
- To compare normal estimated R-factor values (1961–1980) to those associated with periods of climate change (1997–2016);
- To evaluate how the lifespans of reservoirs are affected by possible increases in the R-factor.

2. Material and methods

2.1. Empirical models

In this study, three empirical models were applied to two small catchments in Central Europe: USLE, RUSLE and USPED. Benefits of the Universal Soil Loss Equation (USLE) model include the fact that it requires less site-specific data than more physically based models, as well as its simple structure and ease of application. Nevertheless, USLE-based empirical models do not necessarily simulate the processes appropriate to every study and should therefore only be applied in the range of conditions for which they were developed (Hessel, 2002; Nekhay et al., 2009; De Vente et al., 2013;). Despite the limitations of USLE, however, these models (developed in the USA by Wischmeier and Smith in the 1970s) are still widely applied for predicting and controlling soil loss, as well as for planning soil conservation measurements, especially in developing countries (Onyando et al., 2005; Bhattarai and Dutta, 2007; Ramlal and Baban, 2008; Bagherzadeh, 2014; Ayele et al., 2017). The empirical models chosen for this study are often discussed in Czech and Slovak literature (Gajdová, 1999; Stankoviansky, 1999, 2003; Stankoviansky et al., 2008; Dostál et al., 2014; Kadlec et al., 2014; Kapička et al., 2017) and the USLE-based approach is the recommended methodology in the context of soil erosion modelling for Central Europe (Janeček et al., 2012; Dostál et al., 2014; Kadlec et al., 2014). The Revised Universal Soil Loss Equation (RUSLE) model was developed by Renard et al. (1997) to predict long-term rates of inter-rill and rill erosion in field- or farm-sized units subject to different management practices (; Panagos et al., 2015a; SooHoo et al., 2017; Sujatha and Sridhar, 2018). Finally, the Unit Stream Power based Erosion/Deposition model (USPED) was developed in the 1990s to predict the spatial distribution of erosion and deposition rates in cases of erosion affected by limited transport capacity (Mitášová et al., 1996; Mitáš and Mitášová, 1998). The USPED model has been applied mainly in North America (Liu et al., 2007; Skagen et al., 2016) and Europe (Garcia Rodriguez and Gimenez Suarez, 2012; Lazzari et al., 2015). These three different empirical models (USLE, RUSLE and USPED) were applied to two study sites for this study – the Svacenický Creek catchment (SVC) and the Suchý Creek catchment (SUC) – each with variable natural conditions.

The general USLE equation is (Wischmeier and Smith in 1965):

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

when G is average annual soil loss in t ha^{-1} yr^{-1}, and RKLSCP are the factors reflected the main physical-geographic conditions. Using the pluviometric data (Suppl. II), the R-factor value in MJ mm ha^{-1} h^{-1} $year^{-1}$ was calculated according to the Wischmeier and Smith (1978) equation:

$$R = \sum_{1}^{12} 1.735 \times 10^{\left[1.5 \times \log_{10}\left(P_i^2/P\right) - 0.08188\right]} \tag{2}$$

where P is an annual rainfall amount (mm) and P_i is monthly rainfall amount (mm). The resulting values of R-factor are in Table 1. Rainfall plays a crucial role in soil water erosion, and the erosive force of rainfall is dependent upon its amount and intensity (Panagos et al., 2015b). The erosive force of rainfall is commonly expressed as the R-factor (Wischmeier and Smith, 1965). The R-factor can be calculated using several methodologies in a wide range of temporal and spatial scales, which can, in turn, generate numerous possible results. For example, Krása et al. (2014) presented eight different values of R-factor in the CZE calculated by seven different Czech authors, and the resulting values ranged between 200 and 690 MJ mm ha^{-1} h^{-1} yr^{-1}. Panagos et al. (2015b) determined the R-factor value in the CZE at 524 MJ mm ha^{-1} h^{-1} yr^{-1}. It is obvious that the importance of the R-factor value cannot be underestimated, especially in light of climate change.

The K-factor value was calculated by following equation:

$$100\text{K} = 2.1M^{1.14} \text{ x } 10^{-4} \text{ x } (12 - a) + 3.25(b - 2) + 2.5(c - 3) \quad (3)$$

where M = (% silt + % sand) * (100 - % clay), a is the organic matter content (%), b is the soil structure code (1 is very structured or particulate, 2 is fairly structured, 3 is slightly structured, and 4 is solid), and c is the profile permeability code (1 is rapid, 2 is moderate to rapid, 3 is moderate, 4 is moderate to slow, 5 is slow, and 6 is very slow). Table 1 presents the resulting K-factor values.

The following equation adopted from Mitasova et al. (1996) was used to calculate the LS-factor values in USLE:

$$\text{LS} = (A/22.13)^{1.6}\text{x}(\sin B/0.0896)^{1.3} \quad (4)$$

where A is the upslope contribution factor, B is the slope steepness in degrees. The different computation of LS-factor value in RUSLE model is based on equation in Renard et al. (1997):

$$\text{LS} = \left[\frac{Q_a M}{22.13}\right]^y \text{ x } \left(0.065 + 0.045 \text{ x } S_g + 0.0065 \text{ x } S_g^2\right) \quad (5)$$

where Q_a is the upslope contribution factor, S_g is the slope steepness in percentage, M is grid size (X,Y), and y is dimensionless exponent that assumes the value of 0.2–0.5. Both calculations were based on particular DEMs of both study areas (Suppl. II) and the resulting LS values are shown in Table 1.

The C-factor was based on documented crop rotation in both study areas (Suppl. II, Fig. 1) and factor's values in Table 1 were derived from previous investigations carried out in similar environments in Central Europe (Malíšek, 1992; Gajdová, 1999; Šúri et al., 2002; Janeček et al., 2012).

Visual photo interpretation of air photos and field observations were used to assess the P value. The value was set up to 1 (without support practices; Table 1).

The last applied model is the USPED (Mitáš and Mitášová, 1998; Mitášová et al., 1996). The structures of USLE, RUSLE and USPED implementation into GIS software (ArcMap 10.5 provided by ESRI Company) are presented in Supplement III and IV.

2.2. Soil delivery ratio

In a catchment, part of the soil eroded in an overland region deposits within the catchment before reaching its outlet. The SDR is a ratio of sediment yield to total surface erosion. According to Bagarello et al. (1991), the SDR depends on the contribution area, relief, stream length, bifurcation ratio, the proximity of the sediment source to the stream, and the texture of the eroded material.

Table 1
Factor's input values.

R-FACTOR (MJ mm ha^{-1} h^{-1} yr^{-1})							
Year		2012	2013	2014	2015	2016	2017
Svacenický Creek							
Annual amount of precipitation (mm)		623.2	795.7	640.0	462.2	441.0	656.7
Factor value		339.5	407.9	478.5	633.2	187.3	325.7
Suchý Creek							
Annual amount of precipitation (mm)		525.0	612.5	638.5	494.5	614.6	576.0
Factor value		195.5	496.5	405.0	371.2	389.4	610.4
		Svacenický Creek		*Suchý Creek*			
K-FACTOR (t ha h ha^{-1} MJ^{-1} mm^{-1})		0.017		0.034			
LS-FACTOR (–)							
USLE		0–333.44 ($\bar{x}$ 5.57)		0–403.83 ($\bar{x}$ 1.41)			
RUSLE		0–102.82 ($\bar{x}$ 4.56)		0–313.03 ($\bar{x}$ 1.17)			
P-FACTOR (–)		1		1			
C-FACTOR (–)							
Land use/cover units		Value	Literature				
Arable land	Corn (Zea)	0.72	Janeček et al. (2012)				
	Sorghum (Sorghum)	0.32	Malíšek (1992), Panagos et al. (2015d)				
	Rape (Brassica)	0.22	Janeček et al. (2012)				
	Rye (Secale)	0.17	Janeček et al. (2012)				
	Barley (Hordeum)	0.15	Janeček et al. (2012)				
	Triticale (Triticosecale)	0.15	Janeček et al. (2012)				
	Wheat (Triticum)	0.12	Janeček et al. (2012)				
	Oat (Avena)	0.10	Janeček et al. (2012)				
	Pea (Pisum)	0.05	Janeček et al. (2012)				
	Clover (Trifolium)	0.02	Janeček et al. (2012)				
	Lucerne (Medicago)	0.01	Janeček et al. (2012)				
Non-arable land	Path	0.50	Panagos et al. (2015d)				
	Scrubland	0.20	Panagos et al. (2015d)				
	Orchard, garden	0.10	Malíšek (1992); Boyle et al. (2011)				
	Grassland	0.005	Janeček et al. (2012)				
	Forest	0.001	Boyle et al. (2011); Panagos et al. (2015d); Renard et al. (1997)				
	Paved area	0	a-priori assumption				
	Water body	0	a-priori assumption				

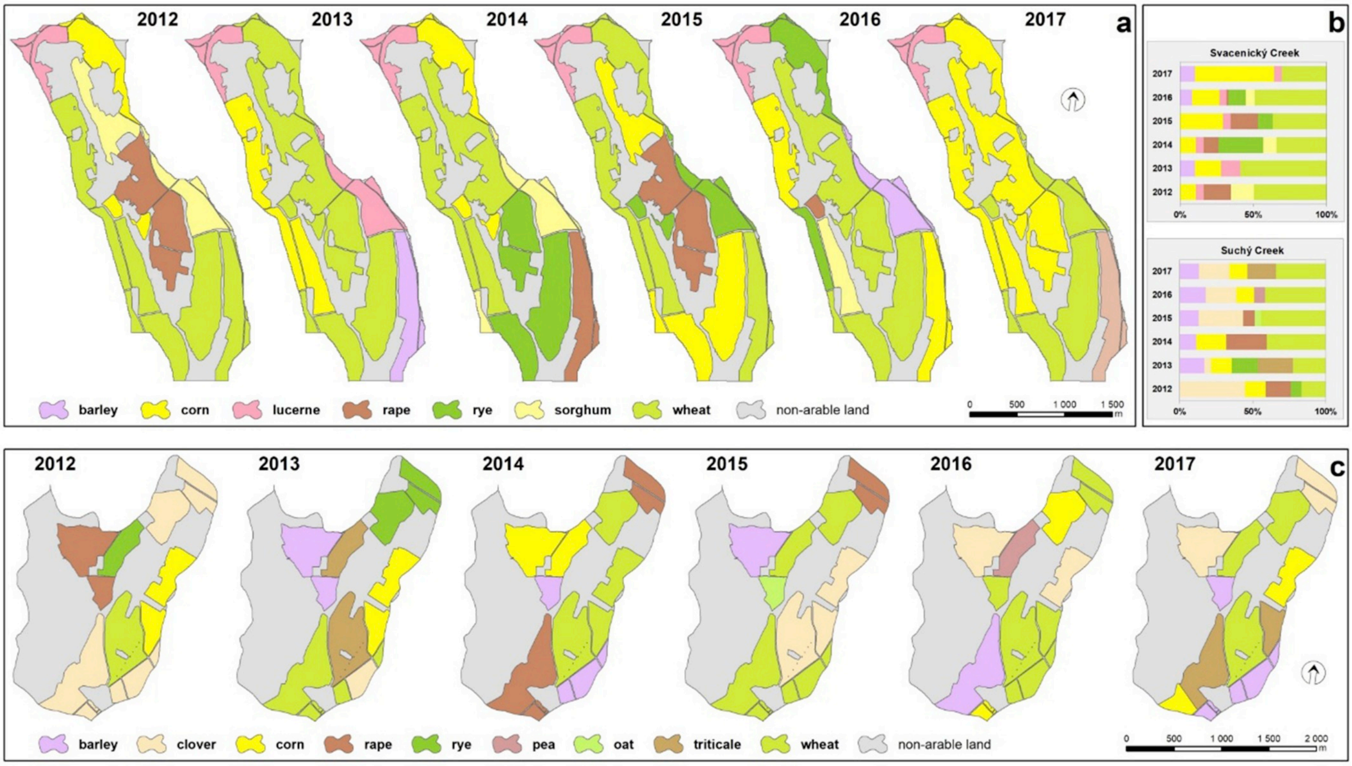

Fig. 1. Annual crop distribution in both catchments: the SVC (a); the SUC (c). The annual percentage of crop distribution in both study areas (b).

The Williams equation from 1977 was chosen in this paper:

$$SDR = 1.366 \text{ x } 10^{-11} \text{ x } A^{-0.0998} \text{ x } s_r^{0.3629} \text{ x } CN^{5.444} \quad (6)$$

where SDR is delivery ratio, A is contribution area in square kilometres, s_r is relief ratio in metres per kilometres, and CN is number of runoff curve. The average annual amount of sediments in the research area is calculated as the reduction of total annual erosion based on chosen empirical equation of the SDR ratio (Janeček et al., 2012).

2.3. The case studies

The Svacenický Creek catchment (SVC) is situated in western Slovakia (SVK) near the frontier with Czechia (CZE) in the middle of the Myjava Hill Land (Fig. 2). The Suchý Creek catchment (SUC) is located in the south-east part of Czechia on the northern border of the Moravian Karst, with a total area of 3.5 km^2 (Fig. 2). Further catchments' information is provided in Fig. 2 and Supplement V.

The Svacenický reservoir (Fig. 2b) was built in 2010 at the bottom of the catchment. According to the project documentation (VODOTIKA, 2008), the height of the embankment dam is 10.25 m and the maximum retention capacity is 215,808 m^3, with a maximum water level of 8.5 m. The modelled retention capacity during the 100-year flood was 207,330 m^3, with a peak discharge of 16.0 m^3/s. This reservoir serves a flood-protection function, and the permanent water level covers approximately 3 ha of the catchment.

The Němčice reservoir (Fig. 2e) is located at the bottom of the SUC catchment and covers 7352 m^2. The dam takes the form of an embankment, with a height of 5.1 m and a length of 206 m. The maximum retention capacity is 67,757 m^3, with a maximum water level of 5.1 m. This semi-dry reservoir was built in 2011 as a flood protection structure. The modelled retention capacity during the 100-year flood was 190,000 m^3, with a peak discharge of 11.5 m^3/s according to information found in the project documentation (AGERIS, 2009).

The natural catchment characteristics of both study sites are dissimilar in almost all parameters (Suppl. VI). It should be remarked that the SVC catchment is almost twice as large as the SUC catchment, but also that the SUC catchment is more consistent and asymmetric. The drainage networks in both are similar except for stream length, but this variable is responsible for significant differences in the drainage texture analysis between catchments. Together with the more variable relief in the SVC catchment, the concentration time of overland flow is shorter where there is a higher value of runoff velocity.

Long-term terrain measurement of sediment budget in small reservoirs is rare both within and outside of Central Europe, and that is why only two reservoirs were investigated in this study. The sediment budget was derived from the bottom's development of sediment in both reservoirs by two different terrain measurements compared to original Digital Elevation Model (DEM) from 2012. An AUV EcoMapper recorded the bathymetry in the Svacenický reservoir during field measurements carried out by the Slovak Academy of Science (SAS) in 2015, 2016, and 2017. This device is capable of moving independently on both the surface and subsurface and performs data logging in water with depths between 1 and 100 m. The EcoMapper is ideal for hydrographic spatial environmental monitoring in coastal and shallow-water applications. Fig. 3 provides the AUV path and the results. The Research Institute for Soil and Water Conservation (VÚMOP) carried out survey of the bottom's development of sediment in the Němčice reservoir during 2014 and 2017. The depth of the bottom was recorded on a 5 × 5 meter grid covering the entire reservoir. The depth was subtracted from the fixed position on the dam construction. The resulting DEMs are presented in Fig. 4.

The input soil data (Table 2) were acquired during a field measurement in 2018 (July/August) and following laboratory analysis of 75 soil samples – 47 samples of soil and 28 samples of sediments – in both catchments (Fig. 5). The 32 intact samples (collected using iron rings) were used for bulk density estimation, and 43 samples were used for organic carbon content estimation and particle-size analysis. Bulk density was calculated as the weight of dry soil (drying in an oven at 105 °C for about 24 h) divided by the total soil volume of the intact core sample.

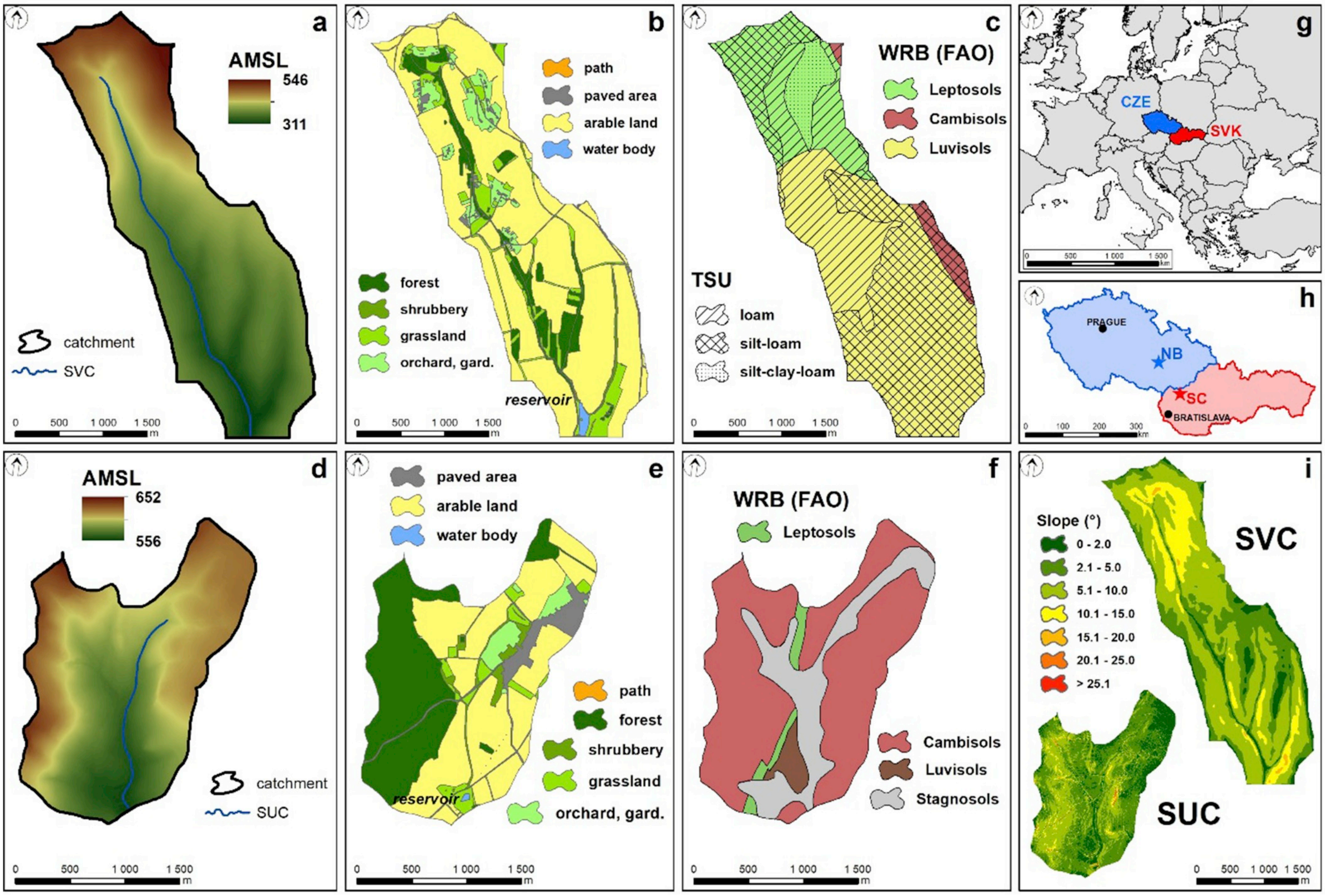

Fig. 2. Location and characteristics of the research areas: Relief (a), land use (b) and soil condition (c) of the SVC; Relief (d), land use (e) and soil condition (f) of the SUC; Localization of both catchments (g,h); Slope steepness in both catchments (i).

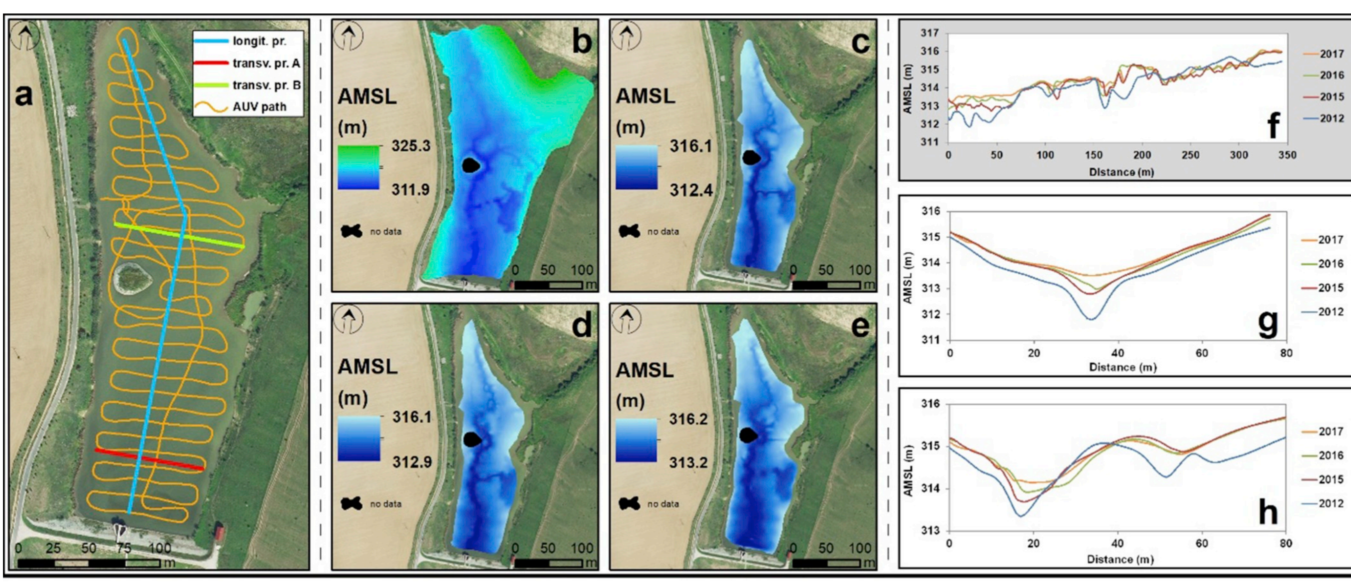

Fig. 3. The evolution of reservoirs' bottoms during 2012 and 2017 in the Svacenický reservoir: the AUV path and longitudinal/transversal profiles (a); DEM of reservoir in 2012 (b), 2015 (c), 2016 (d) and 2017 (e); graphs of bottom's development – longitudinal profile (f), transversal profile A (g) and B (h).

The organic carbon content was determined in a manner similar to the bulk density estimation; however each soil sample (10 g) was dried in an oven at 550 °C for about 4 h. Finally, the Bettersizer S3 Plus (Dandong Bettersize Instruments Ltd.) machine conducted a soil particle-size analysis of 43 samples (2 g). The results of the laboratory analysis are presented in Table 2.

Two time periods were used to determine the R-factor development: 1961–1980 (reference period) and 1997–2016 (investigate period). The

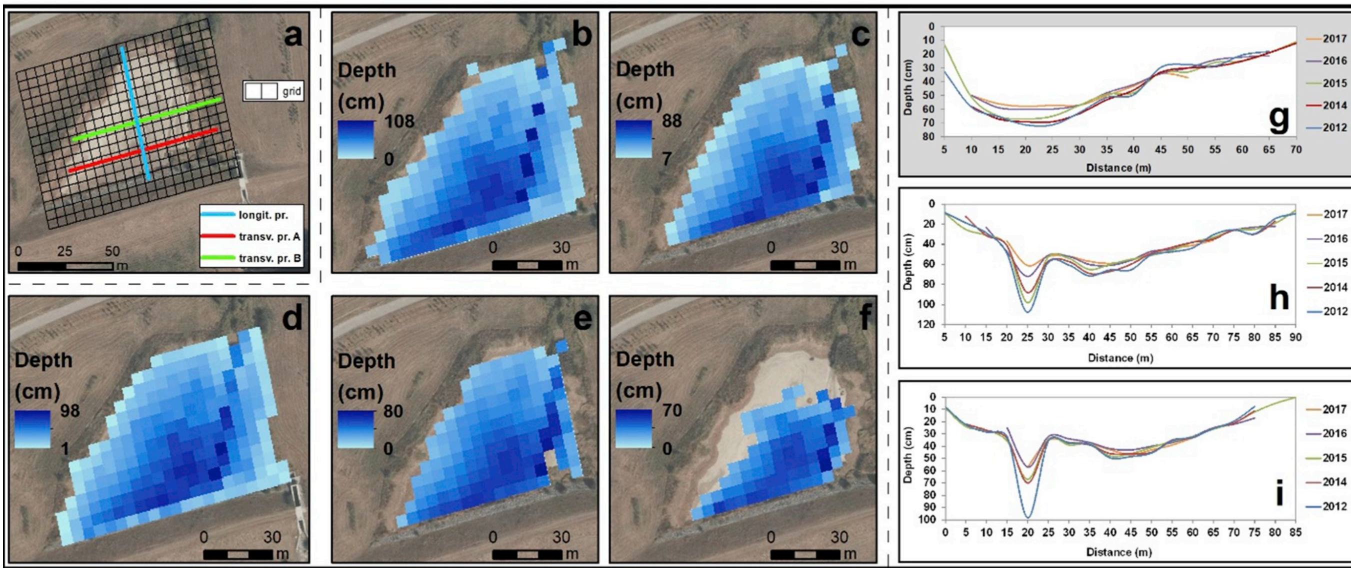

Fig. 4. The evolution of reservoirs' bottoms during 2012 and 2017in the Němčice reservoir: the grid and longitudinal/transversal profiles (a); DEM of reservoir in 2012 (b), 2014 (c), 2015 (d), 2016 (e) and 2017 (f); graphs of bottom's development – longitudinal profile (g), transversal profile A (h) and B (i).

Table 2
Observed soil characteristics.

Study site	Soil particle size (%)			Organic Carbon Content (%)	Bulk Density (g/cm³)
	Sand	Silt	Clay		
SVC	2.8–12.1 ($\bar{x}$ 6.6)	41.4–80.9 ($\bar{x}$ 66.9)	3.6–19.4 ($\bar{x}$ 10.6)	8.8–15.1 ($\bar{x}$ 11.2)	0.982–1.466 ($\bar{x}$ 1.307)
SUC	3.5–11.9 ($\bar{x}$ 6.1)	43.6–85.2 ($\bar{x}$ 71.6)	3.6–15.2 ($\bar{x}$ 6.9)	5.5–9.7 ($\bar{x}$ 7.7)	0.856–1.157 ($\bar{x}$ 1.039)

number of floods in Europe was considered, which doubled in the period 1997–2016 compared to the period 1961–1980 (12.3 events per year compared to 23.5 event per year) and we noted the similar trend for flash floods (Suppl. I). In addition, the period under study was defined as the last possible period to have a complete year dataset because we started our research in 2016. The increase of R-factor has been also taken into account. The year 1997 is known in Central Europe as the first extremely flood-prone year, with tragic consequences in Moravia and west Slovakia. At the same time, the calculated R-factor for the year 1997 (1055.3 MJ mm ha^{-1} h^{-1} yr^{-1}) was the highest in the investigated time period.

2.4. Model efficiency analysis

The model efficiency for each applied erosion model was determined by following statistical analysis based on comparison between observed and simulated sediment budget in the reservoirs:

The Model Efficiency (ME) by Nash and Sutcliff (1970):

$$ME = 1 - \frac{\sum_{i=1}^{n}(Q_{oi} - Q_{si})^2}{\sum_{i=1}^{n}(Q_{oi} - Q_{mean})^2} \quad (7)$$

The Root Mean Square Error (RMSE) in Geza et al. (2009):

$$RMSE = \sqrt{\frac{\sum_{i}^{n}(Q_{si} - Q_{oi})^2}{n}} \quad (8)$$

The Relative Root Mean Square Error (RRMSE) in Van Rompey et al. (2001):

$$RRMSE = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(Q_{oi} - Q_{si})^2}}{\frac{1}{n}\sum_{i=1}^{n}Q_{oi}} \quad (9)$$

The Model Bias (MB) in Safari et al. (2012):

$$MB = \left[\frac{\sum_{i=1}^{n}(Q_{si} - Q_{oi})}{\sum_{i=1}^{n}Q_{oi}}\right] \quad (10)$$

The Modified Correlation Coefficient (r_{mod}) by McCuen and Snyder (1975):

$$r_{mod} = \left[\frac{min\{\sigma_o, \sigma_s\}}{max\{\sigma_o, \sigma_s\}} * r\right] \quad (11)$$

The Aggregated Measure (AM) in Henriksen et al. (2003):

$$AM = \frac{r_{mod} + ME + (1 - |MB|)}{3} \quad (12)$$

where n is number of observations, Q_{mean} is the mean observed value, Q_{oi} is the observed value, Q_{si} is the predicted value, σ_o, σ_s are the standard deviation of observation or simulation respectively, and r as the correlation coefficient between observed and simulated values.

3. Results

3.1. R-factor variability

The change in precipitation caused by global warming is reflected in changes to assessed R-factor values. The correlation between the annual amount of precipitation and the R-factor value is low ($R < 0.5$ with $\alpha = 0.05$), because the monthly amount of precipitation (the distribution of precipitation within the year) plays an important role (=> higher R-factor values when the precipitation distribution is uneven).The mean value of the R-factor calculated at the Myjava meteorological station is 195.4 MJ mm ha^{-1} h^{-1} yr^{-1} for the time period 1961–1980 and 203.6 MJ mm ha^{-1} h^{-1} yr^{-1} for the time period 1997–2016, based on mean total annual and monthly amounts of rainfalls (Table 3). Considering the annual variability between 1997 and 2016, the mean value of the R-factor is 501.2 MJ mm ha^{-1} h^{-1} yr^{-1} (Table 3). This difference can be attributed to climate change, in that higher values were estimated for extreme flood years. For example, the annual value in 1997 was 743.4 mm (the mean is between 650 and 700 mm at the station), but the

Fig. 5. Soil sample and photography localities in the SVC (a catchment; b reservoir) and the SUC (c catchment; d reservoir).

monthly value in July of that year was 232.7 mm, which is the highest recorded monthly amount at the Myjava meteorological station, and the resulting R-factor was 1055.3 MJ mm ha^{-1} h^{-1} yr^{-1}. That year was particularly affected by flooding, with a high occurrence of floods and flash floods across Central Europe, including the Myjava Hill Land.

3.2. *Intensity of soil water erosion/deposition*

The most vulnerable areas threatened by soil water erosion are located in the steepest parts of both catchments and are covered by arable land (Fig. 6). The intensities are much higher in SVC, with values exceeding 10.0 t/ha/yr in almost 25% of the catchment area, than they are in SUC, where such locations cover less than 2% of the total area. The lowest intensities (<1.0 t/ha/yr) in both catchments are commonly located in narrow areas covered by forest and grassland (Fig. 6). The mean intensity of soil erosion ranges from 1.3 t/ha/yr (USPED) to 6.5 t/ha/yr (USLE) in SVC, and from 0.9 t/ha/yr to 1.4 t/ha/yr (USLE) in SUC. The main difference between these catchments is that the areas protected against erosion processes (e.g., forest, shrubbery, grassland) in the SVC catchment cover approximately 27% of the total area, whereas in the SUC catchment the protected areas cover almost 53% of the catchment, located mainly in the western part.

The positions of areas protected against soil and water erosion also correlate to the deposition of eroded material modelled by USPED. In SVC the deposition is very strong in valleys (values > 10.0 t/ha/yr) because of the low slope and because land cover consists mainly of forest, shrubbery, and grassland (Fig. 6). In SUC the deposition occurs in many fragmented locations, which are adjacent to areas with low slope covered by grassland and orchards or gardens (Fig. 6). The locations without erosion or deposition processes respond to paved areas and roads.

Table 3
The mean R-factor value in the Czech Republic (scientific review), calculated mean values in both study areas, and the long-term mean value at the Myjava meteorological station.

Source	R (MJ mm ha^{-1} h^{-1} yr^{-1})	Time period
Janeček et al. (1992)	200	–
Dostál et al. (2006)	570	1962–2001
Dostál et al. (2006)	690	2000–2005
Janeček et al. (2012)	480	(1961) 1971–2000
Hanel (2013)	640	1989–2003
Rožnovský et al. (2013)	690	2003–2012
Panagos et al. (2015b)	524	1961–1999
Svacenický Creek	406.2	2012–2017
Suchý Creek	411.3	2012–2017
Myjava station	195.4	1961–1980
	203.6/501.2	1997–2016

3.3. *Siltation of reservoir*

The observed sediment yield in the Svacenický reservoir (considering a sediment water content of 56.5% according to Hucko and Šumná, 2003) was 4071.6 m^3 during 2012 and 2017. The USPED model presents a good prediction rate of sediment yield of about 7.2% in contrast to the USLE and RUSLE models (Table 4), confirmed by the model efficiency analysis (Table 5) which yielded positive ME (NSE), RRMSE, and AM analysis values.

In the case of the Němčice reservoir, the observed sediment volume was only 160.6 m^3 during 2012 and 2017. This low value is due to the specific construction of the dam; the dike release allows the continuous discharge of water and suspended load from the reservoir. This has

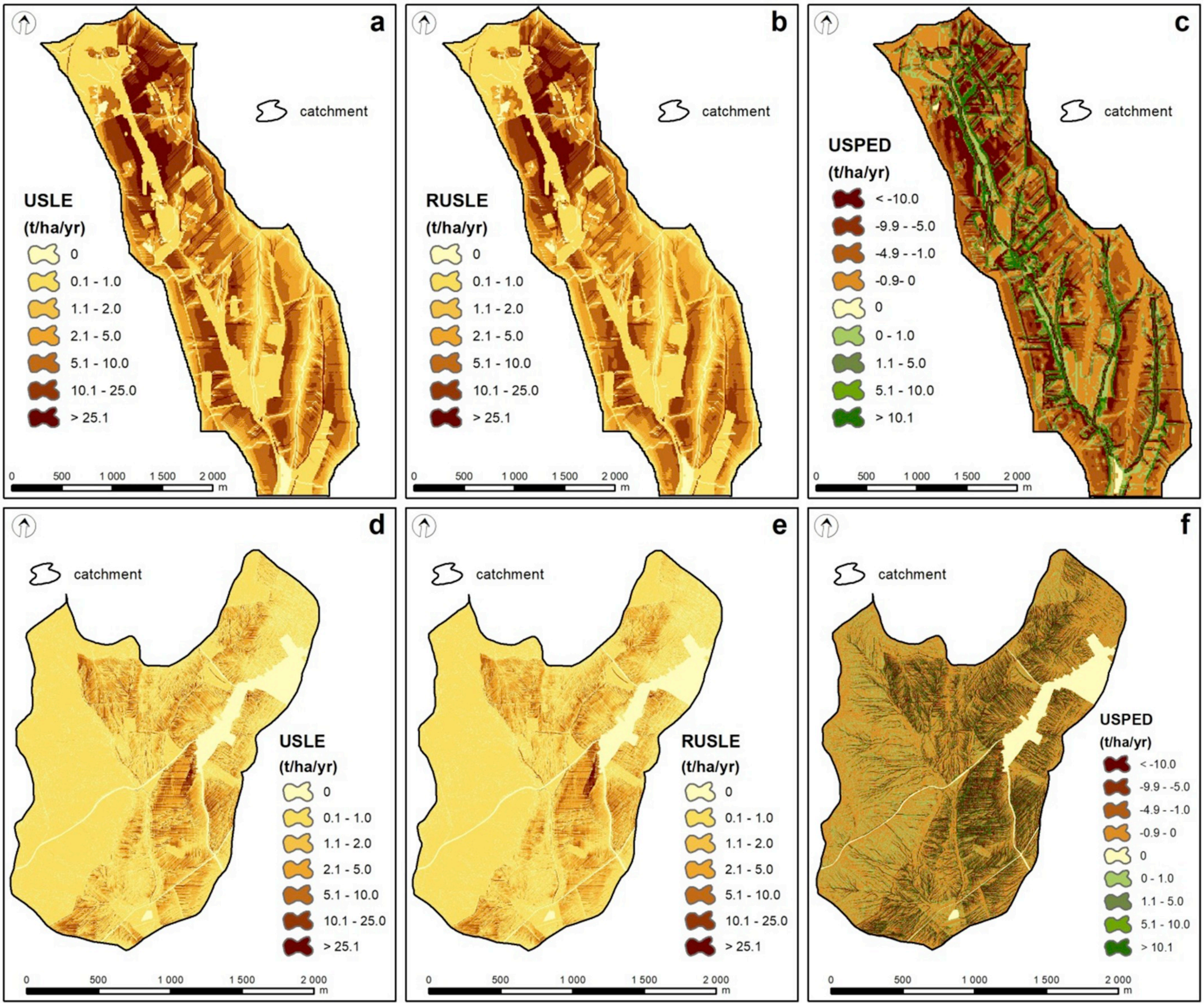

Fig. 6. Spatial distribution of soil erosion and deposition estimated by three empirical models (2012–2017): the SVC (a–c); the SUC (d–f).

resulted in a modelled sediment yield almost ten times higher (USLE and USPED) than the observation (Table 4), corresponding to the negative model efficiency analysis results in Table 5, which included some values out of range (e.g., RRMSE and AM).

The observed annual siltation in the Svacenický reservoir is 678.6 m^3, leading to a predicted total infill of the storage capacity in 318 years,

Table 4
Observed and predicted sediment yield in both catchments (2012–2017).

Model	Average annual intensity of soil loss (t/ha/yr)	Amount of soil loss (t)	SDR	Bulk density	Predicted sediment volume (m^3)	Observed sediment volume (m^3)	Δ (%) PRED/OBS
Svacenický Creek catchment							
USLE	6.5	24,334.0	0.49[a]	1307	9549.5	4071.6	**134.5**
			0.71[b]		13255.4		**225.6**
RUSLE	5.6	21,050.1	0.49[a]	1307	8261.4	4071.6	**102.9**
			0.71[b]		11465.4		**181.6**
USPED	1.3	4397.8	–	1307	3778.0	4071.6	**−7.2**
Suchý Creek catchment							
USLE	1.4	2907.2	0.40[a]	1039	1093.3	160.6	**580.8**
			0.66[b]		1769.5		**1001.8**
RUSLE	1.1	2397.8	0.40[a]	1039	901.7	160.6	**461.5**
			0.66[b]		1459.1		**808.5**
USPED	0.9	1744.2	–	1039	1678.7	160.6	**945.3**

Note:
[a] SCS-CN set for good hydrological conditions.
[b] SCS-CN set for bad hydrological conditions.

Table 5
The results of model efficiency analysis.

Model		ME (NSE)	RMSE (m^3)	RRMSE	MB	r_{mod}	AM		TOTAL
Svacenický Creek catchment									
USLE	[a]	−0.5	1201.8	1.6	1.345	0.011	−0.285	OL	**Bad**
	[b]	−2.6	1842.8	2.5	2.256	−0.005	−1.279	OL	**Bad**
RUSLE	[a]	0.0	993.6	1.3	1.029	0.014	−0.018	OL	**Bad**
	[b]	−1.5	1533.1	2.1	1.816	−0.006	−0.766	OL	**Bad**
USPED		0.8	403.7	0.5	−0.072	0.131	0.629	Good	**Good**
Suchý Creek catchment									
USLE	[a]	−85.1	173.7	5.9	5.8	−0.03	−30.0	OL	**Bad**
	[b]	−248.1	295.4	10.1	10.0	−0.02	−85.7	OL	**Bad**
RUSLE	[a]	−54.2	139.1	4.7	4.6	−0.04	−19.3	OL	**Bad**
	[b]	−161.8	238.9	8.2	8.1	−0.03	−56.3	OL	**Bad**
USPED		−214.9	275.1	9.4	9.5	−0.02	−74.5	OL	**Bad**

Note: [a] SCS-CN set for good hydrological conditions; [b] SCS-CN set for bad hydrological conditions; TOTAL – summarized evaluation of all analyses; OL – number is out of limit; BAD – bad model performance; GOOD – good model performance.

corresponding to the 343 years predicted by the USPED model. The predicted lifespan of the Němčice reservoir, according to observed annual sediment siltation of 26.8 m^3, is 2531 years. As may be expected, the USPED model also predicted much faster reservoir infilling (i.e. total infill of the storage capacity in 242 years). It can be finally stated that the supposed theoretical lifespan of both reservoirs is approximately 300 years if no protection measures are applied. We expect the gradual loos of functionality (e.g., the transformation effect) with progressive decrease of retention capacity.

The correlation analysis presents a relatively high dependence of modelled sediment production on annual R-factor values in both catchments. The correlation coefficient (R) is equable among erosion models ($R = 0.8$) in the SUC catchment. Minimal variability of the correlation coefficient was found in the SVC catchment ($R = 0.7$-0.9). It can therefore be stated that all three applied models are strongly dependent on the R-factor, especially the USPED model ($R = 0.8$-0.9). In the case of the annual observed sediment volume, the dependence on the R-factor and the total annual precipitation amount were relatively low in both catchments. Only in the SVC catchment was there was a high correlation with the R-factor ($R = 0.7$). The results are not significant, with $\alpha = 0.05$, and it was not possible to validate the results due to the small number of available case studies.

The erosion processes minimally correlate with extreme erosion rainfalls (>6.5 mm/15 min) in the SVC catchment ($R = 0.4$). In contrast, the SUC catchment is more dependent on total annual rainfall amounts and on rainfalls >1 mm ($R > 0.8$). These results correspond in part to the catchment behaviour, where the observed sediment volume strongly correlates with >12.5 mm rainfalls ($R = 0.9$) and lightly with >1 mm and >6.5 mm/min ($R < 0.5$) in the SVC catchment. However, in the case of the SUC catchment, there is low correlation ($R < 0.5$) between observed sedimentation and all rainfall categories. The results are not significant, with $\alpha = 0.05$.

The correlation analysis revealed relatively high dependence between the modelled sediment production and the mean annual value of the C-factor ($R = 0.7$). This correlation was found in both catchments and among all three models, except the USPED model in SVC, where the correlation coefficient was lower ($R = 0.4$). The results are not significant, with $\alpha = 0.05$. The rest of the model input factors were not analysed, because the values were constant during the investigated time period.

4. Discussion

4.1. Modelling and parameters

Generally, the setting of input factors (RKLSCP) is a crucial aspect of empirical modelling, affected by numerous approaches and recommendations to determine correct factor values. A scientific review of a number of selected studies partially revealed the wide range of factor input values (Suppl. VII, VIII). In order to combat the variability of input parameters in Europe, new policy developments have been implemented throughout the twenty-first century (e.g., INSPIRE Directive, LUCAS, ESDAC) to facilitate data-sharing and to standardized spatial and temporal data sets (Karydas et al., 2014; Panagos et al., 2015a-e). Notwithstanding, incompatibility still remains at the state (regional) level as a result of recommended national methodologies (e.g., Janeček et al., 2012). Finally, responsibility for selection of an appropriate methodology lies with individual researchers, who must consider the natural conditions of the study area together with the objective of the research. Because the predefined values of all factors are different across the literature, the setting must be carefully chosen to consider the similarities in natural conditions between the investigated area and the area examined in the literature and, if possible, researchers should use their own measured or collected data.

4.2. Performance of empirical based models for sediment estimation

USLE-based models are widely used globally to model long-term rill, interrill, or sheet erosion (e.g., Onyando et al., 2005; Beskow et al., 2009; Karydas et al., 2014; ; Kapička et al., 2017). Despite recommendations to use USLE-based models only in the range of conditions they were developed for (Hessel, 2002; De Vente et al., 2013), USLE-based models do seem to be appropriate in conditions ranging from farm-sized units to large-scale catchments (Krasa et al., 2005; Bhattarai and Dutta, 2007; Skagen et al., 2016). Presented results support claims that the models are suitable for spatial localization of intensive erosion processes, and in the case of temporal development the models are also capable of revealing annual variability of intensities in any (pre)defined period of time. It can be stated that the choice of an appropriate erosion model is difficult, and it is necessary to understand the natural conditions of the investigated area in order to make an appropriate choice (Hessel, 2002; Nekhay et al., 2009; Geza et al., 2009; De Vente et al., 2013; Denjean et al., 2017; Benavidez et al., 2018).

However, the reviewed publications also indicate overestimations of modelled sediment yield calculated by USLE-based models compared the real observed sedimentation in reservoirs (Suppl. IX). In addition, model accuracy is variable, but it can be noted that the RUSLE and USLE models are particularly suitable for modelling of sediment yield in comparison to observation. The best matches were found for the Kartalkaya Dam catchment in Turkey (0.2%), the Zagozdzonka catchment in Poland (−4.7 to −14.1%), the Ksob catchment in Algeria (−7.2%), and the Somersby Plateau and MacDonald Ranges in Australia (7.3%). In other research areas the differences between observation and prediction are much higher comparable to our results (e.g., Hlavčová et al., 2018; Zao et al., 2018). The notable differences between modelled and observed sediment yields indicate the difficulty posed by the model's simplification of the natural phenomenon of erosion. On the one hand, the variability of the natural processes is incompatible with an empirical approach, but on the other hand it should be remarked that the results from empirical models are often comparable to observations (Suppl. XI).

To predict catchment sediment yield, the USLE-based models (except the USPED model) are usually extended by SDR to evaluate the basin sediment transport efficiency (Ferro and Minacapilli, 1995; Dickinson and Collins, 1998; Krasa et al., 2005; Taguas, 2011; Di Stefano and Ferro, 2017), and the equation given by Williams (1977) was used in this paper with satisfying results according to the literature. The resulting mean annual siltation derived by using the USPED model was comparable to real observation only in the SVC catchment. The rest of the results were insufficient for precise estimation of reservoir siltation. While the overestimated values produced by the models had been predicated, the difference between observed and modelled sediment yield was unexpectedly higher (>100%).

The modelled mean catchment intensities of soil water erosion found in our study are lower compared to the results of other Czech and Slovak scientists (Suppl. X). The empirical model most often applied in these studies was USLE; Hlavčová et al. (2018), for example, applied a USLE + SDR approach to the same area of SVC as our study, and Uhlířová (2007) applied a USLE approach in SUC. In the case of Hlavčová et al. (2018), results were obtained for five land cover scenarios in which the total arable land was covered by one type of cultivated crop. Their results show that the winter wheat scenario is sufficient for modelling of potential soil water erosion in SVC and are (relatively) comparable to our results from USLE. On the other hand, Uhlířová (2007) presented higher values of intensities in SUC, but the calculations in this study were performed for chosen runoff lines and not for the entire catchment. Other studies examined used different localities with varying natural conditions; their differing results may also have been the result of the use of standardized R-factor values.

4.3. Effect of changing precipitation on erosion

The intensity of soil water erosion and deposition is strongly associated with the character of the rainfall-runoff processes in a particular catchment. The main variables affecting erosion and deposition are the intensity and amount of rainfall. Rainfall parameters have been transformed by current global climate change (Zolina et al., 2014; Dolák et al., 2017; Trnka et al., 2017;), which has caused the number of extreme rainfall-runoff processes to rise (Van Rompaey et al., 2001; Nelson and Booth, 2002; Abril and Knight, 2004; Hlavčová et al., 2016). Climate change in Central Europe is confirmed by the rise in annual mean temperatures during the last decades (Suppl. XIb). The annual total amount of precipitation, in contrast, seems not to have obviously changed (Suppl. XIa). Notwithstanding, climate change has dramatically increased the frequency and intensity of rainfalls. In the case of the Czech Republic, the precipitation amount is predicted to grow by 10%–13% by the end of the twenty-first century, in comparison to the referenced period prior to climate change (1981–2010) (Štěpánek et al., 2019). The Slovak Hydrometeorological Institute (SHMÚ) states that the number of rain events with durations of 5–240 min has been increasing during the last decades (SHMÚ, 2019). In fact, erosive rains (15-min intensities) occur 2.5 to 4.7 times per year (which corresponds to our analysis in Suppl. XII) and this number is expected to rise in the future, especially between the months of April and October (SHMÚ, 2019).

The increase in the number of the floods in Europe, recorded by several authors (Suppl. I), and the rising number of flash floods in Central Europe could be explained by the increasing number of rain events with durations of 5–240 min (SHMÚ, 2019), also characterized as erosive rains. According to IPCC (2014), not only will such flood events increase, but dry seasons with abnormally low amounts of precipitation are also expected. The number of flash floods caused by intensive rainfalls is extensive, and the total number has increased since 1950 (Suppl. I). The trend during the last twenty years has been stagnated for high levels, in spite of the dry season, which corresponds mainly with the decrease in the total number of floods (not only flash floods). However, flash floods have been occurring more often in Central Europe since 1995.

In erosion modelling the rainfall parameters are represented by the R-factor value. It was predicted that the intensification of rainfall would force changes to occur in the R-factor value in this study. The results significantly confirmed the rise of the R-factor from those of the normal climate period (1961–1980) to those of the chosen period influenced by climate change (1997–2016). Krása et al. (2014) also state that the R-factor value estimated for the Czech Republic is much higher nowadays, and Dostál et al. (2006) estimate higher R-factor values for the period 2000–2005 than for the period 1962–2001. It must also be noted that here the applied methodology is based on monthly and annual rainfall amounts (Wischmeier and Smith, 1978), which was proven by here presented results to be the suitable approach for revealing annual variability of the R-factor, rather than on the total kinetic energy of rain and the maximum 30-min intensity (Wischmeier and Smith, 1978), using the mean annual values for the chosen time period (Krása et al., 2014).

In CZE, several authors have analysed rainfall data to estimate the R-factor based on different time periods. These studies used equations based on the total kinetic energy of rain and the maximum 30-min intensity. Their results are shown in Table 3 together with the newest assessment by Panagos et al. (2015b), and it is obvious that the lower values of the R-factor were calculated for earlier time periods. Those studies are commonly used as the recommended methodologies in CZE and SVK. If it is problematic to obtain information about the total kinetic energy of rain and the maximum 30-min intensity, the R-factor calculation based only on monthly and annual precipitation can be considered the reliable method (especially in study areas equipped with their own meteorological stations). The calculated values of the R-factor are comparable to values based on the literature (Table 3).

The dependence of the observed sediment production on the annual total rainfall amount and annual R-factor is different to that of the modelled sediment production. The modelled sediments are strongly dependent on the R-factor ($R > 0.7$), but the observed sediments are marginally dependent on both parameters. Nearing et al. (2017) discuss the role of the R-factor and rainfalls in USLE-based erosion modelling and find, significantly, that the erosion process is caused by a combination of natural conditions in the study area; it is hard to say which of the six empirical factors the main driver is. There is a statistical relationship between raindrop kinetic energy and splash detachment (Nearing and Bradford, 1985), but the soil loss from areas dominated by splash and sheet-flow are not correlated to splash detachment (Bradford and Foster, 1996). If the soil loss is caused mainly by the interrill erosion or the rill erosion is active on the slope, then the major driving factor is the runoff rate (Nearing et al., 2017).

4.4. Life time of small reservoirs and their maintenance under climate change

The two presented terrain approaches, as well as the method for measuring the sediment budget of the reservoir, can be influenced by several effects, such as water vegetation, the depth of the reservoir, and variable sediment water content. Notwithstanding, the results from the SUC catchment hint at another influencing factor: namely, the construction of the dam. In this case, there is “a missing” sediment budget corresponding to material which was allowed to pass continuously through the dike release in unknown amounts. Discovery of this correspondence can be highlighted as a key outcome of this paper, because the continuous measurement of uncontrolled sediment release from small reservoirs is problematic for small local municipalities, in contrast to measurement of the same from large reservoirs, which are often administrated by regional or state authorities (e.g., river basin enterprises). Despite these problems, the scientific community remains interested in small reservoirs (Erskine et al., 2002; Boix-Fayos et al., 2008; Banasik et al., 2012; Bussi et al., 2013; Di Stefano et al., 2017; Hlavčová et al., 2018; Zhao et al., 2018) and these results provide helpful support for local authorities.

The intensity of erosion processes is expressed mainly in terms of the intensity and amount of rainfall. Together with the above-mentioned information, rainfall parameters are evolving, and rain events are becoming more intensive (SHMÚ, 2019), and it has been documented that low-frequency high-magnitude rainfall events are responsible for disastrous flashing of sediments (Březková et al., 2011; Stankoviansky et al., 2010; Hlavčová et al., 2016). This has resulted in the intensification of erosion processes and rising levels of sediment yield, which must be taken as one of the main soil threats worldwide (Boardman and Poesen, 2006; De Vente et al., 2013; Santoro et al., 2019). There is also expected to be an increase in trapped sediment in reservoirs, leading to a decrease in the storage capacity and lifespan of affected reservoirs (Bazoffi et al., 1996; Bussi et al., 2013; Lee and You, 2013; Borrelli et al., 2014). In this study, the presented results show the predicted total infilling (on average) of both investigated reservoirs over the course of 300 years. These findings suggest that estimations of sediment retention should be an integral consideration in the planning and maintenance of reservoirs; such estimations are rarely considered in the case of small reservoirs (Uhlířová, 2007; Yin et al., 2011; Hlavčová et al., 2018).

5. Conclusion

This study has examined methods for estimating sedimentation rates in two small reservoirs, with consideration of the importance of the R-factor. Three empirical models were applied for this purpose and the following conclusions can be made.

Firstly, the tested models (USLE, RUSLE and USPED) successfully predicted erosion rates, but overestimated the reservoir siltation (except in the case of the USPED-based model in the SVC catchment). Accounting for suspended sediment yield at reservoir outlets may improve model performances and, more importantly, provide substantial information on water quality in streams (e.g., Nitrate directive (CD, 1991)).

Secondly, the annual mean rainfall erosivity factor has increased by a factor of 1.04 due to changes in precipitation patterns between the periods 1961–1980 and 1997–2016. Sediment production was highly, but not significantly, correlated ($\alpha = 0.05$) to the mean annual rainfall erosivity factor, while the correlation of observed sediment to the R-factor was lower.

Thirdly, the proposed method based on USPED model was successful for evaluating the lifespan of the Svacenický reservoir. We demonstrated that the lifespan of the selected reservoirs will be shortened by accelerated siltation more than a third. The strong relationship between erosion rates and changes in precipitation patterns indicate that we can likely expect faster siltation in reservoirs, due to more intensive erosion processes anticipated over the course of the twenty-first century. The increasing occurrence of high-intensity precipitation may lead to both higher sediment production and greater rates of sedimentation. Furthermore, the proposed methods and results serve as freely available support tools for municipalities in which assessment of reservoir functionality is relevant. The USPED model provides satisfactory results, but further improvement of datasets (e.g., continuous sediment measurement) is recommended in order to answer managers' requirements with regard to planning for protection from flash floods, water quality, and water quantity measures in changing climate conditions.

Acknowledgements

This work has been supported by the Slovak Research and Development Agency under Contract No. APVV-15-0497, the Specific Research project at Masaryk University (MUNI/A/1251/2017 Integrated research of environmental changes in the landscape sphere II), and the Ministry of Education, Youth and Sports of the Czech Republic project no. CZ.02.1.01/0.0/0.0/16_013/0001708 (Ecopolaris). This paper was also prepared with the support of the project No. VEGA 2/0025/19 and the Institutional support MZE-RO0218.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2019.109958.

Author contribution statement

David Honek: Conceptualization, Methodology, Investigation, Writing-Original Draft, Visualization. **Monika Šulc Michalková**: Supervision, Writing-Review and Editing, Visualization. **Anna Smetanová**: Methodology, Writing-Review and Editing. **Valentin Sočuvka**: Methodology, Investigation. **Yvetta Velísková**: Methodology, Investigation. **Petr Karásek**: Methodology, Investigation. **Jana Konečná**: Methodology, Investigation. **Zuzana Németová**: Resources. **Michaela Danáčová**: Resources, Writing-Review and Editing.

References

Abril, B., Knight, D.W., 2004. Stabilising the Paute river in Ecuador. Proceedings of the ICE. Civ. Eng. 156, 32–38. https://doi.org/10.1680/cien.2004.157.1.32.
Act No 114/1992, 1992. Coll. The Act on the Nature and Landscape Protection. Ministry of the Environment of the Czech Republic, Prague, p. 92.
Act No 183/2006, 2006. Coll. The Building Act. Ministry of Regional Development of the Czech Republic, Prague, p. 50.
Act No 254/2001, 2001. Coll. The Water Act. Ministry of the Environment of the Czech Republic, Prague, p. 116.
AGERIS, 2009. Dry Retention Reservoir on Němčice Creek, Field Roads Pv1 and Pv2 in the Cadastral Area of Němčice and Pv15 in Cadastral Area of Žďár U Blanska. Brno, 10-26-2009. Situation plan, p. 1.
CD, 1991. European Commission, Concerning the protection of waters against pollution caused by nitrates from agricultural sources. Council Directive), Brussels, 12-12-1991. 91/676/EEC (1991), 13 pp.
Ayele, G.T., Teshale, E.Z., Yu, B., Rutherfurd, I.D., Jeong, J., 2017. Streamflow and sediment yield prediction for watershed prioritization in the upper blue nile river basin, Ethiopia. Water 9, 782–809. https://doi.org/10.3390/w9100782.
Baade, J., Franz, S., Reichel, A., 2012. Reservoir siltation and sediment yield in the Kruger national park, South Africa: a first assessment. Land Degrad. Dev. 23, 586–600. https://doi.org/10.1002/ldr.2173.
Bagarello, V., Ferro, V., Giordano, G., 1991. Contributo alia valutazione del fattore di deflusso di Williams e del coefficiente di resa solida per alcuni bacini idrografici siciliani. Rivista di Ingegneria Agraria, Anno XXII, 238–251.
Bagherzadeh, A., 2014. Estimation of soil losses by USLE model using GIS at Mashhad plain, Northeast of Iran. Arab. J. Geosci. 7, 211–220. https://doi.org/10.1007/s12517-012-0730-3.
Banasik, K., Górski, D., Popek, Z., Hejduk, L., 2012. Estimating the annual sediment yield of a small agricultural catchment in central Poland. IAHS Publ. 356, 267–275.
Bazoffi, P., Baldassarre, G., Vacca, S., 1996. Validation of PISA2 model for automatic assessment of reservoir sedimentation. In: Albertson, M.L., et al. (Eds.), Proceedings of the International Conference on Reservoir Sedimentation. Fort Collins, Colorado State University, pp. 519–528.
Benavidez, R., Jackson, B., Maxwell, D., Norton, K., 2018. A review of the (Revised) Universal Soil Loss Equation (R/USLE): with a view to increasing its global applicability and improving soil loss estimates. Hydrol. Earth Syst. Sci. Discuss. 1–34. https://doi.org/10.5194/hess-22-6059-2018.
Beskow, S., De Mello, C.R., Darrell, N.L., Curi, N., Viola, M.R., Avanzi, J.C., 2009. Soil erosion prediction in the Grande River Basin, Brazil using distributed modelling. Catena 79, 49–59. https://doi.org/10.1016/j.catena.2009.05.010.
Bhattarai, R., Dutta, D., 2007. Estimation of soil erosion and sediment yield using GIS at catchment scale. Water Resour. Manag. 21, 1635–1647. https://doi.org/10.1007/s11269-006-9118-z.
Black, P.E., 1996. Watershed Hydrology. Ann Arbor press, Chelsea.
Boardman, J., Poesen, J., 2006. Soil Erosion in Europe. John Wiley & Sons, Ltd., New York.
Boix-Fayos, C., De Vente, J., Martínez-Mena, M., Barbéra, G.G., Castillo, V., 2008. The impact of land use change and check-dams on catchment sediment yield. Hydrol. Process. 22, 4922–4935. https://doi.org/10.1002/hyp.7115.
Borrelli, P., Märker, M., Panagos, P., Schütt, B., 2014. Modeling soil erosion and river sediment yield for an intermountain drainage basin of the Central Apennines, Italy. Catena 114, 45–58. https://doi.org/10.1016/j.catena.2013.10.007.
Boyce, R.C., 1975. Sediment routing with sediment delivery ratios. Present and Prospective Technology for Predicting Sediment Yields and Sources. US Department of Agriculture, Publ. ARS-S-40, Washington D.C., pp. 61–65
Boyle, J.F., Plater, A.J., Mayers, C., Turner, S.D., Stroud, R.W., Weber, J.E., 2011. Land use, soil erosion, and sediment yield at Pinto Lake, California: comparison of a

simplified USLE model with the lake sediment record. J. Paleolimnol. 45, 199–212. https://doi.org/10.1007/s10933-010-9491-8.
Bussi, G., Rodriguez-Lloveras, X., Francés, F., Benito, G., Sánchez-Moya, Y., Sopena, A., 2013. Sediment yield model implementation based on check dam infill stratigraphy in a semiarid Mediterranean catchment. Hydrol. Earth Syst. Sci. 17, 3339–3354. https://doi.org/10.5194/hess-17-3339-2013, 2013.
Březková, L., Šálek, M., Novák, P., Kyznarová, H., Jonov, M., 2011. New methods of flash flood forecasting in the Czech Republic. In: Hřebíček, j., Schimak, G., Denzer, R. (Eds.), Environmental Software Systems. Frameworks of eEnvironment. ISESS 2011, IFIP Advances in Information and Communication Technology, vol. 359. Springer, Berlin, Heidelberg, pp. 550–557. https://doi.org/10.1007/978-3-642-22285-6_59.
CTS 75 2410, 2011. Small Water Reservoirs. Czech Office for Standards, Metrology and Testing, Prague, p. 48.
De Vente, J., Poesen, J., Verstraeten, G., Govers, G., Vanmaercke, M., Van Rompaey, A., Arabkhedri, M., Boix-Fayos, C., 2013. Predicting soil erosion and sediment yield at regional scales: where do we stand? Earth Sci. Rev. 127, 16–29. https://doi.org/10.1016/j.earscirev.2013.08.014.
Denjean, B., Altamirano, M.A., Graveline, N., Giordano, R., Van Der Keur, P., Moncoulon, D., Weinberg, J., Máñez Costa, M., Kozinc, Z., Mulligan, M., Pengal, P., Matthews, J., Van Cauwenbergh, N., López Gunn, E., Bresch, D.N., 2017. Natural assurance scheme: a level playing field framework for Green-Grey infrastructure development. Environ. Res. 159, 24–38. https://doi.org/10.1016/j.envres.2017.07.006.
Di Stefano, C., Ferro, V., 2017. Testing the modified sediment delivery model (MOSEDD) at SPA2 experimental basin, Sicily (Italy). Land Degrad. Dev. 28, 1557–1567. https://doi.org/10.1002/ldr.2684.
Dickinson, A., Collins, R., 1998. Predicting erosion and sediment yield at the catchment scale. In: Penning de Vries, E.W.T., et al. (Eds.), Soil Erosion at Multiple Scales, Principles and Methods for Assessing Causes and Impacts. CABI Publishing, New York, Oxon, pp. 317–342.
Dolák, L., Řezníčková, L., Dobrovolný, P., Štěpánek, P., Zahradníček, P., 2017. Extreme precipitation totals under present and future climatic conditions according to regional climate models. In: Vačkář, D., et al. (Eds.), Climate Change Adaptation Pathways from Molecules to Society. Global Change Research Institute, Czech Academy of Sciences, Brno, pp. 27–37.
Dong, X., Guo, H., Zeng, S., 2017. Enhancing future resilience in urban drainage system: green versus grey infrastructure. Water Res. 124, 280–289. https://doi.org/10.1016/j.watres.2017.07.038.
Dostál, T., Vrána, K., Krása, J., Jakubíková, A., Schwarzová, P., David, V., Nováková, H., Bečvář, M., Veselá, J., Kavka, P., 2006. Metody a Zpusoby Predikce Povrchoveho Odtoku, Eroznich a Transportnich Procesu V Krajine. Annual Research Report from COST634 Action. CTU, Prague.
Dostál, T., Krása, J., Kavka, P., Vrána, K., Devátý, J., Kadlec, V., Novotný, I., Kulířová, P., Heřmanovská, D., Papaj, V., Kapička, J., Váňová, V., 2014. Využití Dat a Nástrojů GIS a Simulačních Modelů K Navrhování TPEO. VÚMOP, ČVUT, Praha.
EC, 2011. European commission, towards better environmental options for flood risk management. Brussels, 3-8-2011. DG ENV D 1, 16, 2011) 236452.
EEA, 2017. Green Infrastructure and Flood Management. Promoting Cost-Efficient Flood Risk Reduction via Green Infrastructure Solutions. Copenhagen, Technical report No 14/2017.
Erskine, W.D., Mahmoudzadeh, A., Myers, C., 2002. Land use effects on sediment yields and soil loss rates in small basins of Triassic sandstone near Sydney, NSW, Australia. Catena 49, 271–287. https://doi.org/10.1016/S0341-8162(02)00065-6.
Ferro, V., Minacapilli, M., 1995. Sediment delivery processes at basin scale. Hydrol. Sci. 40, 703–717. https://doi.org/10.1080/02626669509491460.
Ferro, V., Porto, P., 2000. Sediment delivery distributed (SEDD) model. J. Hydraul. Eng. 5, 411–422, 10.1061/-ASCE)1084-0699(2000)5:4(411).
Fu, B., Liu, Y., Lü, Y., He, C., Zeng, Y., Wu, B., 2011. Assessing the soil erosion control service of ecosystems change in the Loess Plateau of China. Ecol. Complex. 8, 284–293. https://doi.org/10.1016/j.ecocom.2011.07.003.
Gajdová, J., 1999. Vplyv Eróznych Procesov V Poľnohospodársky Využívanej Krajine Na Kvalitu Vodných Tokov. Bratislava, VÚVH.
Garcia Rodriguez, J.J., Gimenez Suarez, M.C., 2012. Methodology for estimating the topographic factor LS of RUSLE3D and USPED using GIS. Geomorphology 175–176, 98–106. https://doi.org/10.1016/j.geomorph.2012.07.001.
Geza, M., Poeter, E.P., McCray, J.E., 2009. Quantifying predictive uncertainty for a mountain-watershed model. J. Hydrol. 376, 170–181. https://doi.org/10.1016/j.jhydrol.2009.07.025.
Hanel, M., 2013. Information of the author – not published results within the project VG 20122015092. Erosion Runoff - Increased Risk of the Residents and the Water Quality Exposure in the Context of the Expected Climate Change. T.G. Masaryk Water Research Institute, Prague.
Henriksen, H.J., Troldborg, L., Nyegaard, P., Sonnenborg, T.O., Refsgaard, J.C., Madsen, B., 2003. Methodology for construction, calibration and validation of a national hydrological model for Denmark. J. Hydrol. 280, 52–71. https://doi.org/10.1016/S0022-1694(03)00186-0.
Hessel, R., 2002. Modelling Soil Erosion in a Small Catchment on the Chinese Loess Plateau. PhD thesis. Utrecht University, Netherlands.
Hlavčová, K., Kohnová, S., Borga, M., Horvát, O., Šťastný, P., Pekárová, P., Majerčáková, O., Danáčová, Z., 2016. Post-event analysis and flash flood hydrology in Slovakia. J. Hydrol. Hydromechanics 64, 304–315. https://doi.org/10.1515/johh-2016-0041.
Hlavčová, K., Kohnová, S., Velísková, Y., Studvová, Z., Sočuvka, V., Ivan, P., 2018. Comparison of two concepts for assessment of sediment transport in small agricultural catchments. J. Hydrol. Hydromechanics 66, 404–415. https://doi.org/10.2478/johh-2018-0032.
Hucko, P., Šumná, J., 2003. Verification of the System of Sediment Disposal from Water Management Reservoirs. VÚVH, Bratislava.
IPCC, 2014. In: Barros, V.R., Field, C.B., Dokken, D.J., Mastrandrea, M.D., Mach, K.J., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E. S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 688.
Janeček, M. (Ed.), 1992. Ochrana Zemědělské Půdy Před Erozí. ÚVTIZ, Pargue.
Janeček, M. (Ed.), 2012. Ochrana Zemědělské Půdy Před Erozí. ČZU, Prague.
Junakova, N., Balintova, M., 2012. Predicting of soil loss in the tisovec catchment, Slovakia. Chem. Eng. Trans. 28, 265–270. https://doi.org/10.3303/CET1228045.
Kadlec, V., Dostál, T., Vrána, K., Kavka, P., Krása, J., Devátý, J., Podhrázská, J., Pochop, M., Kulířová, P., Heřmanovská, D., Novotný, I., Papaj, V., 2014. Navrhování Technických Protierozních Opatření. VÚMOP, ČVUT, Praha.
Kapička, J., Novotný, I., Žížala, D., 2017. Monitoring Zemědělské Půdy – Závěrečná Zpráva. VÚMOP, Praha.
Karydas, C.G., Panagos, P., Gitas, I.Z., 2014. A classification of water erosion models according to their geospatial characteristics. Int. J. Dig. Earth 7, 229–250. https://doi.org/10.1080/17538947.2012.671380.
Kondolf, G.M., Gao, Y.X., ANnandale, G.W., Morris, G.L., Jiang, E.H., Zhang, J.H., Cao, Y. T., Carling, P., Fu, K.D., Guo, Q.C., Hotchkiss, R., Peteuil, C., Sumi, T., Wang, H.W., Wang, Z.M., Wei, Z.L., Wu, B.L., Wu, C.P., Yang, C.T., 2014. Sustainable sediment management in reservoirs and regulated rivers: experiences from five continents. Earth's Fut. 2, 256–280. https://doi.org/10.1002/2013EF000184.
Krasa, J., Dostal, T., Van Rompaey, A., Vaska, J., Vrana, K., 2005. Reservoirs' siltation measurements and sediment transport assessment in the Czech Republic, the Vrchlice catchment study. Catena 64, 348–362. https://doi.org/10.1016/j.catena.2005.08.015.
Krása, J., Středová, H., Dostál, T., Novotný, I., 2014. Rainfall erosivity research on the territory of the Czech Republic. In: Rožnovský, J., Litschmann, T. (Eds.), Mendel a Bioklimatologie, pp. 1–20. Brno.
Lazzari, M., Gioia, D., Piccarreta, M., Danese, M., Lanorte, 2015. Sediment yield and erosion rate estimation in the mountain catchments of the Camastra artificial reservoir (Southern Italy): a comparison between different empirical methods. Catena 127, 323–339. https://doi.org/10.1016/j.catena.2014.11.021.
Lee, B.-S., You, G.J.-Y, 2013. An assessment of long-term overtopping risk and optimal termination time of dam under climate change. J. Environ. Manag. 121, 57–71. https://doi.org/10.1016/j.jenvman.2013.02.025.
Lewis, S.E., Bainbridge, Z.T., Kuhnert, P.M., Sherman, B.S., Henderson, B., Dougall, C., Cooper, M., Brodie, J.E., 2013. Calculating sediment trapping efficiencies for reservoirs in tropical settings: a case study from the Burdekin Falls Dam, NE Australia. Water Resour. Res. 49, 1017–1029. https://doi.org/10.1002/wrcr.20117.
Liu, J., Liu, S., Tieszen, L.L., Chen, M., 2007. Estimating soil erosion using the USPED model and consecutive remotely sensed land cover observations. In: Wainer, G.A. (Ed.), Gabriel A. Wainer: Proceedings of the 2007 Summer Computer Simulation Conference. SCSC, San Diego, pp. 1–7, 2007.
Malíšek, A., 1992. Optimálna Dĺžka Svahu V Závislosti Na Vodnej Erózii. Vedecké Práce. VÚPÚ Bratislava, pp. 203–220.
McCuen, R.H., Snyder, W.M., 1975. A proposed index for comparing hydrographs. Water Resour. Res. 11, 1021–1024. https://doi.org/10.1029/WR011i006p01021.
Mekonnen, M., Keesstra, S.D., Stroosnijder, L., Baartman, J.E.M., Maroulis, J., 2014. Soil conservation through sediment trapping: a review. Land Degrad. Dev. 26, 544–556. https://doi.org/10.1002/ldr.2308.
Mitáš, L., Mitášová, H., 1998. Distributed soil erosion simulation for effective erosion prevention. Water Resour. Res. 34, 505–516. https://doi.org/10.1029/97WR03347.
Mitášová, H., Hofierka, J., Zlocha, M., Iverson, L.R., 1996. Modelling topographic potential for erosion and deposition using GIS. Int. J. GIS 10, 629–641. https://doi.org/10.1080/02693799608902101.
Nash, J.E., Sutcliffe, J.V., 1970. River flow forecasting through conceptual models. J. Hydrol. 10, 280–292. https://doi.org/10.1016/0022-1694(70)90255-6.
Nearing, M.A., Bradford, J.M., 1985. Single Waterdrop Splash Detachment and Mechanicla Properties of Soils. Soil. Sci. Soc. Am. J. 49, 547–552. https://doi.org/10.2136/sssaj1985.03615995004900030003x.
Nearing, M.A., Yin, S., Borelli, P., Polyakov, V.O., 2017. Rainfall erosivity: an historical review. Catena 157, 357–362. https://doi.org/10.1016/j.catena.2017.06.004.
Nekhay, O., Arriaza, M., Boerboom, L., 2009. Evaluation of soil erosion risk using Analytic Network Process and GIS: a case study from Spanish mountain olive plantations. J. Environ. Manag. 90, 3091–3104. https://doi.org/10.1016/j.jenvman.2009.04.022.
Nelson, E.J., Booth, D.B., 2002. Sediment sources in an urbanizing, mixed land-use watershed. J. Hydrol. 264, 51–68. https://doi.org/10.1016/S0022-1694(02)00059-8.
Nesshöver, C., Assmuth, T., Irvine, K.N., Rusch, G.M., Waylen, K.A., Delbaere, B., Haase, D., Jones-Walters, L., Keune, H., Kovacs, E., Krauze, K., Külvik, M., Rey, F., Van Dijk, J., Vistad, O.I., Wilkinson, M.E., Wittmer, H., 2016. The science, policy and practice of nature-based solutions: an interdisciplinary perspective. Sci. Total Environ. 579, 1215–1227. https://doi.org/10.1016/j.scitotenv.2016.11.106.
Onyando, J., Kisoyan, P., Chemelil, M.C., 2005. Estimation of potential soil erosion for river Perkerra catchment in Kenya. Water Resour. Manag. 19, 133–143. https://doi.org/10.1007/s11269-005-2706-5.
Panagos, P., Borelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L., Alewell, C., 2015a. The new assessment of soil loss by water erosion in Europe. Environ. Sci. Policy 54, 438–447. https://doi.org/10.1016/j.envsci.2015.08.012.

Panagos, P., Ballabio, C., Borrelli, P., Meusburger, K., Klik, A., et al., 2015b. Rainfall erosivity in Europe. Sci. Total Environ. 511, 801–814. https://doi.org/10.1016/j.scitotenv.2015.01.008.
Panagos, P., Borrelli, P., Meusburger, K., 2015c. A new European slope length and steepness factor (LS-Factor) for modelling soil erosion by water. Geoscience 5, 117–126. https://doi.org/10.3390/geosciences5020117.
Panagos, P., Borelli, P., Meusburger, K., Alewell, C., Lugato, E., Montanarella, L., 2015d. Estimating the soil erosion cover-management factor at the European scale. Land Use Policy 48, 38–50. https://doi.org/10.1016/j.landusepol.2015.05.021.
Panagos, P., Borelli, P., Meusburger, K., Van Der Zanden, E.H., Poesen, J., Alewell, C., 2015e. Modelling the effect of support practices (P-factor) on the reduction of soil erosion by water at European scale. Environ. Sci. Policy 51, 23–34. https://doi.org/10.1016/j.envsci.2015.03.012.
Rahmani, V., Kastens, J.H., Denoyelles, F., Jakubauskas, M.E., Martinko, E.A., Huggins, D.H., Gnau, C., Liechti, P.M., Campbell, S.W., Callihan, R.A., Blackwood, A. J., 2018. Examining storage capacity loss and sedimentation rate of large reservoirs in the central U.S. Great plains. Water 10, 1–17. https://doi.org/10.3390/w10020190.
Ramlal, B., Baban, S.M.J., 2008. Developing a GIS based integrated approach to flood management in Trinidad, West Indies. J. Environ. Manag. 88, 1131–1140. https://doi.org/10.1016/j.jenvman.2007.06.010.
Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., Yoder, D.C., 1997. Predicting Soil Erosion by Water: a Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). USDA-ARS, Washington.
Richter, B.D., Thomas, G.A., 2007. Restoring environmental flows by modifying dam operations. Ecol. Soc. 12, 1–26.
Rožnovský, J., Středová, H., Středa, T., 2013. Analýza Souboru Podkladů K Určení a Výpočtu R Faktoru, Přehled Dosavadních Postupů. výzkumná zpráva. CHMI, Brno.
Safari, A., De Smedt, F., Moreda, F., 2012. WetSpa model application in the distributed model intercomparison project (DMIP2). J. Hydrol. 418–419, 78–89. https://doi.org/10.1016/j.jhydrol.2009.04.001.
Santoro, S., Pluchinotta, I., Pagano, A., Pengal, P., Cokan, B., Giordano, R., 2019. Assessing stakeholders' risk perception to promote Nature Based Solutions as flood protection strategies: the case of the Glinščica river (Slovenia). Sci. Total Environ. 655, 188–201. https://doi.org/10.1016/j.scitotenv.2018.11.116.
SHMÚ, 2019. Rast Extrémnosti Viacdenných Úhrnov Zrážok Na Slovensku. http://www.shmu.sk/sk/?page=2049&id=965. (Accessed 20 March 2019).
Skagen, S.K., Burris, L.E., Granfors, D.A., 2016. Sediment accumulation in Prairie wetlands under a changing climate: the relative roles of landscape and precipitation. Wetlands 36, 383–395. https://doi.org/10.1007/s13157-016-0748-5.
SooHoo, W.M., Wang, C., Li, H., 2017. Geospatial assessment of bioenergy land use and its impacts on soil erosion in the U.S. Midwest. J. Environ. Manag. 190, 188–196. https://doi.org/10.1016/j.jenvman.2016.12.057.
Stankoviansky, M., 1999. Geomorphic response of agricultural landscape to land use changes associated with introduction of large-scale farming in Slovakia. In: Jambor, P., et al. (Eds.), Soil Conservation in Large-Scale Land Use. Bratislava, ESSC, SSCRI, pp. 49–58.
Stankoviansky, M., 2003. Geomorphic Response to Environmental Changes in the Territory of the Myjava Hill Land. Comenius University, Bratislava.
Stankoviansky, M., Koco, Š., Pecho, J., Jenčo, M., Juhás, J., 2008. Geomorphic response of dry volley basin to large-scale land use changes in the second half of the 20th century and problems with its reconstruction. Morav. Geogr. Rep. 16, 11–24.
Stankoviansky, M., Minár, J., Barka, I., Bonk, R., Trizna, M., 2010. Investigating muddy floods in Slovakia. Land Degrad. Dev. 21, 336–345. https://doi.org/10.1002/ldr.1004.
Štěpánek, P., Trnka, M., Meitner, J., Dubrovský, M., Zahradníček, P., Lhotka, O., Skalák, P., Kyselý, J., Farda, A., Semerádová, D., 2019. Očekávané Klimatické Podmínky V České Republice – Část I. Změna Základních Parametrů. Report of project SustES, CzechGlobe, Brno.
Sujatha, E.R., Sridhar, V., 2018. Spatial prediction of erosion risk of a small mountainous watershed using RUSLE: a case-study of the palar sub-watershed in Kodaikanal, south India. Water 10, 1–17. https://doi.org/10.3390/w10111608.
Šúri, M., Cebecauer, T., Hofierka, J., Fulajtár, E., 2002. Soil erosion assessment of Slovakia at a regional scale using GIS. Ecology 21, 404–422.
Taguas, E.V., Moral, C., Ayuso, J.L., Pérez, R., Gómez, J.A., 2011. Modeling the spatial distribution of water erosion within a Spanish olive orchard microcatchment using the SEDD model. Geomorphology 133, 47–56. https://doi.org/10.1016/j.geomorph.2011.06.018.
Trnka, M., Brázdil, R., Vizina, A., Dobrovolný, P., Mikšovský, J., Štěpánek, P., Hlavinka, P., Řezníčková, L., Žalud, Z., 2017. Droughts and drought management in the Czech Republic in a changing climate. In: Wilhite, D.A., et al. (Eds.), Drought and Water Crises: Integrating Science, Management, and Policy. CRC Press, Taylor & Francis, Boca Raton, pp. 461–480.
Uhlířová, J., 2007. Survey of efficiency of erosion and flood control measures at the Němčický stream. Soil Water Res. 2, 85–95. https://doi.org/10.17221/2102-SWR.
Van Rompaey, A.J.J., Verstraeten, G., Van Oost, K., Govers, G., Poesen, J., 2001. Modelling means annual sediment yield using a distributed approach. Earth Surf. Process. Landforms 26, 1221–1236. https://doi.org/10.1002/esp.275.
VODOTIKA, 2008. Polder Svacenický Creek. Bratislava, 10-01-2008. Project documentation, p. 35.
Williams, J.R., 1977. Sediment delivery ratio determined with sediment and runoff models. In: Erosion and Solid Matter Transport in Inland Waters. IAHS-AISH pub No. 122, pp. 168–179.
Wischmeier, W.H., Smith, D.D., 1965. Rainfall-Erosion Losses from Cropland East of the Rocky Mountains. USDA, Washington.
Wischmeier, W.H., Smith, D.D., 1978. Predicting Rainfall Erosion Losses – A Guide to Conservation Planning. USDA, Washington.
Wohl, E.E., Cenderelli, D.A., 2000. Sediment deposition and transport patterns following a reservoir sediment release. Water Resour. Res. 36, 319–333. https://doi.org/10.1029/1999WR900272.
Yin, X.-A., Yang, Z.-F., Petts, G.E., 2011. Reservoir operating rules to sustain environmental flows in regulated rivers. Water Resour. Res. 47, 1–13. https://doi.org/10.1029/2010WR009991.
Zhao, G., Mu, X., Jiao, J., Gao, P., Sun, W., Li, E., Wei, Y., Huang, J., 2018. Assessing response of sediment load variation to climate change and human activities with six different approaches. Sci. Total Environ. 639, 773–784. https://doi.org/10.1016/j.scitotenv.2018.05.154.
Zolina, O., Simmer, C., Kapala, A., Shabanov, P., Becker, P., Mächel, H., Gulev, S., Groisman, P., 2014. Precipitation variability and extremes in central Europe: new view from STAMMEX results. Bull. Am. Meteorol. Soc. 99, 995–1002. https://doi.org/10.1175/BAMS-D-12-00134.1.