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PREDICTION OF SEDIMENT INFLOW TO THE KLUSOV-HERVARTOV RESERVOIR

Sediment transport through water erosion is an environmental problem, having widespread and serious negative impact on agricultural production and mainly on water quality. Sediments reduce the stream capacity, reservoir's accumulation capacity and act as the ultimate sink of many pollutants (nutrients, heavy metals, pesticides). For assessment the water management and environmental impact of sediments on water quality, first, it is necessary to determine the total amount of sediments deposited in reservoirs, often originated from erosion of agricultural production areas.

This paper deals with the method for determination of the sediment quantity in the small water basin Klusov-Hervartov, which is based on combining the soil loss calculation using the Universal Soil Loss Equation and sediment delivery ratio. The calculation is supplemented with the determining of the detached sediment amount during 5 cropping periods in the year depending on land use in the river catchment's area. Total quantity of sediments trapped in reservoir is determined according to the reservoir trapping efficiency by using Brune and Dendy method. Soil loss is computed based on the particular crop rotations in the catchment during 10 years.

1. Introduction

Soil erosion is a major form of land degradation and has been recognized as a severe environmental problem since late 18th century. In Europe soil erosion affects large areas and it is estimated that about 17% of the total land area is affected. However, large differences exist in Europe, which reflect climate, land-use, topography and hydrology. In fact enhanced erosion due to deforestation, agricultural activity, urbanisation and other land-use changes is one of the most important changes occurring globally at the Earth's surface [1]. In Slovakia soil erosion belongs to the most frequent soil degradation processes and is mainly due to water (39,7%) and to a lesser extent to wind (5,5%).

Sediments, originated by erosion, cause silting of the small water basins, that belongs to the important problems in water management mainly due to the reducing of the basin's accumulation capacity. Sediments also affect water quality in reservoirs because they play an important role by being the ultimate sink of pollutants. For the purposes of water quality monitoring in reservoirs, it is necessary to determine the total amount of sediments deposited in these water basins, often originated from erosion of agricultural production areas.

In our works [2-4] we aimed at the following of sediment quality detached through water erosion. Nowadays, it should be rather a preference to predict the erosion and its control. The prediction of reservoir sedimentation is mainly based on mathematical modelling, although empirical methods are still in use.

2. Material and methods

2.1. Study area description

This study was conducted in the Tisovec river catchment, located in the east of Slovakia, in Bardejov district. The area of this watershed is about 6,0 km^2 and it falls in the the Topla partial river basin. Annual average discharge is 0,045 m$^3 \cdot$ s^{-1}. About 1,5 km eastward from the Hervartov village, Klusov-Hervartov reservoir is located at an altitude of 343 m above sea level. Average depth of Klusov-Hervartov reservoir is 3,5 m, surface area 2,2 ha and its total capacity is about 72 000 m^3. It was built for fishing, irrigations, recreation and for retention of high water.

The average annual rainfall is about 670 mm, with maximum in summer months. The mean annual temperature is about 8°C with a maximum of 20°C in the month of July and a minimum of –3°C in January. Majority of land has slope more than 8%. Soil types of the watershed are, in general, planosols, cambisols and albic luvisols. From the point of soil texture, medium heavy soils (sandy loam) occur in this area. And according to the content of skeleton in the soil, slightly stony soils lead.

The land use of the catchment was found to be mixed type. The upstream part and middle part of the Tisovec catchment is an area mainly covered with forest (39,2%) and pastures (21,7%), while the lower part is an arable land (21,4%) mainly used for cereals (spring barley, winter wheat), corn silage and winter oilseed rape growing. The rest of the land area is for other uses.

2.2. Model description

Determination of sediment quantity deposited in water reservoir was conducted in the Klusov-Hervartov reservoir, to assess annual soil erosion and sediment yield.

In 2004, Slovak Water Management Enterprise realized the siltation measurements of this reservoir. Quantities of deposited eroded sediments in reservoir are given in Tab. 1. According to the measuring it was detected that reservoir siltation processes during 19 years (1986-2004) resulted in the reduction of its useful capacity about 33%. Therefore this reservoir was run the water off from 2005 to 2007.

Results given in Tab. 1 will be compared with values obtained from calculation of the sediment quantity trapped in the reservoir.

Table 1. Measurement results of Klusov reservoir siltation

Year	Watershed area [km^2]	Total reservoir capacity [m^3]	Sediment quantity [m^3]
1986	6,0	72 188,00	0
2004	6,0	47 680,70	24 507,30

The Universal Soil Loss Equation (USLE) [5] and sediment delivery ratio (SDR) [6] equation were applied to the watershed to calculate sediment yield (the amount of sediment measured at a point on the waterway), respectively. Total quantity of sediments trapped in the reservoir was determined according to the reservoir trapping efficiency using Brune's and Dendy's method [7]. Soil loss was computed based on the particular crop rotations in the catchment during 10 years (1998-2007).

Soil loss estimation in the Tisovec river catchment

USLE, the most widely accepted and utilized soil loss equation, computes the average annual soil loss for a given site (plot) as the product of six major factors whose most likely values at a particular location can be expressed numerically [5, 8]. The soil loss equation is:

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

where: G – represents the potential long term average annual soil loss in tons per hectare,
R – the rainfall and runoff factor by geographic location [$\mathrm{MJ \cdot ha^{-1} \cdot cm \cdot hod^{-1}}$],
K – the soil erodibility factor [$\mathrm{t \cdot ha \cdot h \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}}$],
L, S – the length slope gradient factor,
C – the crop/vegetation and management factor,
P – the support practice factor.

Estimation of sediment delivery ratio in the Tisovec river catchment

To predict the average annual sediment yield from the catchment, the equation by Williams was used [6]:

$$SDR = 1{,}366 \cdot 10^{-11} \cdot F^{-0{,}0998} \cdot RP^{0{,}3629} \cdot CN^{5{,}444} \tag{2}$$

where: F – drainage area [km^2],
RP – the relief/length ratio [m · km^{-1}],
CN – the long-term average SCS curve number.

Estimation of sediments trapped in Klusov reservoir

Klusov reservoir sediment trap efficiency, the fraction of the sediment transported into a reservoir that is deposited in that reservoir, was expressed using an equation by Dendy, who added more data to Brunes's curve and developed a prediction equation for the median curve [9]:

$$A = 100 \cdot 0{,}97^{0{,}19^{\log\frac{C}{I}}} \tag{3}$$

where: A – trap efficiency [%],
C – volume of the reservoir [m^3],
I – an annual outflow of the reservoir [m^3 · year^{-1}].

3. Results and discussion

The average annual R factor, representing the erosivity of the climate at a particular location, was R = 22,43 MJ · ha^{-1} · cm · h^{-1} determined for investigated area according to statistical values obtained from historical weather records derived by Malisek [10] for Bardejov station. The determination of the K factor was based on the soil textures which exist in the Tisovec river catchment by using the code of the relevant evaluated pedo-ecological unit for each plot individually. The LS factor used in the USLE considers the effect of topography on erosion and it is an essential parameter to quantify the erosion generated due to the influence on surface runoff speed. This factor was determined separately based on the map at a scale of 1:10 000 for each outflow profile (Fig. 1).

The C and P factors are related to the land-use and are reduction factors to soil erosion vulnerability. These factors represent the ratio of soil loss from a given vegetal cover, support practice, type of soil and slope. These are important factors in USLE, since then represent the conditions that can be easily changed to reduce erosion. Therefore, it is very important to have good knowledge concerning land-use in the basin to generate reliable C factor values.

The C factor resulting from this calculation is a generalized C factor value for a specific crop that does not account for crop rotations or climate and annual rainfall distribution for the different agricultural regions of the country. Because erosion varies according to the height of plant cover from the ground, also the C factor changes as the plants grow and the state of the soil surface alters. Therefore, for more accurate calculation in our study, the average annual C factor for crop rotation in followed watershed ($C_{VP,watershed}$), used in USLE equation, was determined as a weighted mean of C_{P1} a C_{P2} values, given for two plots (1004/1 and 2001/1) of arable land located in vicinity of reservoir. The reason of this hypothesis is the fact, that the Tisovec catchment falls from the point of farmed land to Klusov agricultural cooperative, where all plots have similar soil characteristic, especially topographically characteristics and cover crops and management. The crop rotations for two followed plots are given in Tab. 2.

Fig. 1. Outflow profiles in the Tisovec catchment

The average annual $C_{r,i}$ factor in *i*-year for followed plot (1004/1, 2001/1) were computed as a sum of corrected partial values by Wischmeier and Smith divided into five periods for each of the main periods of the cropping cycle (rough fallow, seedling, establishment, growing and maturing crop, residue or stubble field) according to equation [11]:

$$C_{r,i} = \sum_{i=1}^{5} C_i \cdot \Delta R_i \tag{4}$$

where: $C_{r,i}$ – the average annual C factor in *i*-year for followed plot,
C_i – tabular value of C factor by Wischmeier and Smith pertaining to crop in *i*-cropping period,
ΔR_i – redistribution of R factor in corresponding *i*-cropping period.

Table 2. Crop rotation for plots 1004/1 and 2001/1 during 10 years

Year	**Crop**	
	plot 1004/1	**plot 2001/1**
1998	winter oilseed rape	corn silage
1999	triticale	spring barley
2000	corn silage	triticale
2001	winter wheat	winter oilseed rape
2002	winter oilseed rape	triticale
2003	winter wheat	pea
2004	potatoes	winter wheat
2005	winter wheat	spring barley
2006	spring barley	winter rye
2007	winter oilseed rape	winter oilseed rape

The *C* values for each land use of two followed plots in vicinity of reservoir can be found in Tab. 3. The *P* factor was considered 1,0, due to the lack of information and maps about this factor. The values of *K* and *LS* factors are shown in Tab. 4. This table also shows the results of total average annual soil loss from arable land in the Tisovec watershed.

The total sediment yield from the catchment (Tab. 5) was estimate based on the total average annual soil loss from arable land in the catchment (soil loss from other areas was expressed by *SCS* curve numbers [12]). Calculated value of the relief/length ratio was $RP = 41{,}885\ \mathrm{m \cdot km^{-1}}$, average SCS curve numbers were calculated based on the land use for individual soil hydrological classes according to the average crop rotation in followed watershed (used the same method as in the average annual *C* factor calculation). Predominating soil hydrological class in watershed is *C*. The long-term average *SCS* curve number for arable land in the Tisovec catchment represents the value $CN = 84{,}583$ and for catchment it was $CN = 77{,}9$.

Table 3. The average annual *C* factor in *i*-year for followed plots 1004/1 and 2001/1

Plot 1004/1											
Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	C_{P1}
$C_{r,i}$ factor	0,284	0,299	0,649	0,070	0,199	0,282	0,557	0,089	0,314	0,295	**0,304**
Plot 2001/1											
Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	C_{P2}
$C_{r,i}$ factor	0,492	0,095	0,236	0,283	0,282	0,316	0,248	0,142	0,233	0,218	**0,254**
$\boldsymbol{C_{VP,\ watershed}}$											**0,277**

Table 4. Soil loss from arable land in Tisovec catchment

Pro-file	**Length**	**Slope**	***K* factor**	***LS* factor**	**$C_{VP,\ watsh.}$ factor**	**Profile area**	**Plot**	***G***	***G***
	[m]	**[%]**	**[$t \cdot ha \cdot hod \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$]**	**[–]**	**[–]**	**[ha]**		**[$t \cdot ha^{-1} \cdot year^{-1}$]**	**[$t \cdot year^{-1}$]**
1	388	8,80	0,30	4,059	0,277	15,63	1004/1	7,57	118,29
2	980	10,49	0,30	8,375	0,277	18,46	2001/1	15,61	288,21
3	180	10,17	0,40	3,424	0,277	3,53	3003/1	8,51	30,04
4	200	8,87	0,35	2,947	0,277	3,06	3005/1	6,41	19,62
5	708	10,97	0,35	7,617	0,277	16,84	2003/1	16,57	279,01
6	786	10,37	0,39	7,367	0,277	35,36	3101/1	17,86	631,39
7	900	13,54	0,25	11,944	0,277	35,58	2203/2	18,56	660,23
Total						**128,46**			**2026,79**

Table 5. Sediment yield in Tisovec catchment

Land use	**Area *F***	**CN_{VP}**	***SDR***	***G***	***SL***	***SL****	**$SL_{19years}$**
	[km^2]	**[–]**	**[–]**	**[$t \cdot year^{-1}$]**	**[$t \cdot year^{-1}$]**	**[$m^3 \cdot year^{-1}$]**	**[m^3]**
Arable land	1,285	84,58	–	2026,79	–	–	–
Permanent grass	1,301	71	–	0	–	–	–
Forests	2,352	73	–	0	–	–	–
Build up areas	0,458	82	–	0	–	–	–
Water areas	0,270	100	–	0	–	–	–
Other areas	0,335	90	–	0	–	–	–
Total/average	**6,000**	**77,9**	**0,879**	**2026,79**	**1781**	**1370**	**260339**

***** average sediment bulk density is considered 1,3 $t \cdot m^{-3}$

Klusov reservoir sediment trap efficiency was determined based on these characteristics:

- Klusov reservoir volume (*C*): 60 310 m^3,
- an annual outflow of the reservoir (*I*): 0,045 $m^3 \cdot s^{-1} \Rightarrow 1{,}419 \cdot 10^6$ $m^3 \cdot year^{-1}$,
- *C*/*I* ratio: 0,04249.

Trapping efficiency calculated using equation (3) is 74,3%. The total amount of sediments deposited in Klusov reservoir during 19 years was 19 340,60 m^3.

Calculated total amount of sediments deposited in Klusov reservoir was compared with value, obtained from sediment measurements in this reservoir (Tab. 1). The difference between calculated and measured values is 21%. The reason is probably the fact, that manual method of chosen the characteristic profiles was used. Also the result could be affected by determining the *R* factor, which values are lower in Slovak conditions in comparison with other neighboring countries. In Slovakia, the *R* factor values range from 4 to 48 $\mathrm{MJ \cdot ha^{-1} \cdot cm \cdot h^{-1}}$, in Czech Republic it is from 44 to 85 $\mathrm{MJ \cdot ha^{-1} \cdot cm \cdot h^{-1}}$. The highest value was recorded in Austria and it was 185 $\mathrm{MJ \cdot ha^{-1} \cdot cm \cdot h^{-1}}$ [13]. On the basis of these findings, it is suitable to take the *R* factor revision realizing into account like it was in Czech Republic. The result could be also influenced using the Brune's and Dendy's method for estimation of sediment trap efficiency, because this correlation is considered for normal ponded reservoirs. It is not recommended for use in determining trap efficiencies of de-silting basins, dry reservoirs and reservoirs with extreme sediment inflow.

4. Conclusion

The paper is focused on the calculation the total quantity of sediments trapped in the Klusov-Hervartov reservoir. Combination of empirical methods, the Universal Soil Loss Equation (USLE) and sediment delivery ratio (SDR) equation, were applied to the watershed to calculate sediment yield (the amount of sediment measured at a point on the waterway), respectively. Total quantity of sediments trapped in reservoir was determined according to the reservoir trapping efficiency using Brune's and Dendy's method. Soil loss was computed based on the particular crop rotations in the catchment during 10 years.

Calculation results were compared with values obtained from the siltation measurement of the Klusov reservoir. The difference between calculated and measured values was 21%. The reason is probably the fact, that manual method of chosen the characteristic profiles was used. Also the result could be affected by determining the *R* factor, which values are lower in Slovak conditions in comparison with other neighbouring countries. The result could be also influenced using the Brune's and Dendy's method for estimation of sediment trap efficiency, because this correlation is considered for normal ponded reservoirs. On the basis of these findings, it is suitable to take the *R* factor revision realizing into account like it was in Czech Republic.

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